

BAY-DELTA OVERSIGHT  
COUNCIL  
DRAFT

**BRIEFING PAPER ON  
DELTA LEVEE AND CHANNEL  
MANAGEMENT ISSUES**

**Bay-Delta Oversight Council**

**December 1993**

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DELTA LEVEE AND CHANNEL MANAGEMENT ISSUES**

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# INTRODUCTION

## **INTRODUCTION**

### **Briefing Materials on Delta Levee and Channel Management Issues**

This briefing package is meant to provide basic information on to Delta levees, and channels. The three categories of issues presented are general structural integrity issues, issues relating to seismic stability, and levee and channel maintenance issues related to the Senate Bill 34 program.

Also included, is a representative spectrum of perspectives regarding these topics submitted by various affected agencies. Time constraints did not allow for canvassing all agencies and concerned public groups, however, we believe that the coverage provided does encompass a fairly comprehensive identification of the major issues.

The Executive Summary seeks to provide an overview of the material contained herein. It deserves emphasis, however, that the Summary should not be considered a substitute for the full text of the issue papers. Rather, it is meant to provide merely a snapshot of the major points raised since the characterization and flavor of the entire prepared pieces simply cannot be replicated in the Summary.

Perspective papers are reproduced as submitted. The BDOC staff has not attempted to edit, interpret or otherwise characterize the issues or concerns being raised. The Executive Summaries of the perspectives offered represent a sincere attempt to objectively highlight the key points raised. It is here acknowledged that, especially with regard to data, the summaries are cursory at best.

The first section of the package covers general levee stability issues. The second section of the package presents a summary of seismic stability issues relating to Delta levees. In the last section a summary is presented of issues and conflicting priorities which have surfaced during the SB-34 program. Also, included in this final section is a discussion of the innovative techniques which have been employed to address these conflicts in priorities between flood protection and fish and wildlife resources.

Following the discussion papers, prepared comments are included, representing particular perspectives and concerns relating to the levee issues as submitted by affected State, Federal and local agencies, as well as a cross-section of other experts in the field.

# **EXECUTIVE SUMMARY**

## **EXECUTIVE SUMMARY**

### **GENERAL DELTA LEVEE ISSUES**

#### **DELTA LEVEE SEISMIC STABILITY ISSUES**

#### **INTRODUCTION**

Without levees, the Delta, as we know it, would not exist. Delta levees serve many functions, from serving as wildlife habitat and protecting wildlife habitat on the islands, to playing an important role in maintaining Delta water quality and, of course, providing flood protection. Levees, and the channels maintained by them, are also critical to the Delta's role as the hub of the state's water transfer system.

Reclamation of the Delta began in the 1800s. Since that time, the height of Delta levees, relative to land side elevations, has increased from about five to twenty-five feet, generally because of subsidence of the islands. Many of the Delta's levees were built in a piecemeal fashion over several decades. In most cases, they were engineered without the benefit of modern scientific knowledge of geology, hydrology, geophysics or subsidence (the lowering of peat island interior land levels as a result of soil erosion and microbial decomposition accelerated by agricultural activity). Consequently, there has been and continues to be uncertainty about their ability to continue to protect Delta resources.

As a consequence of subsidence, land elevations in the Delta are, for the most part, much lower than waterway elevations. This requires that Delta levees act as water barriers at all times, complicating their repair and maintenance.

With respect to the subsidence problem, it is important to note the distinction between areas where peat soils underlie islands and those where mineral soils do. Generally, those islands composed of mineral soils do not suffer from a significant subsidence problem. However, the peat soil islands are subject to the lowering of land levels through subsidence, caused by microbial decomposition of the peat soils as they are exposed to the air. Those islands most affected by subsidence and thus with the lower interior levels and greater levee heights are located in the central and western Delta, while mineral islands tend to be found around the Delta perimeter with higher interior land levels, including some which are above sea level.

The Delta Flood Protection Act of 1988 (SB-34) sought to provide a focus for coordinated engineering investigations and improvement projects for non-project levees, with regard to overall design, maintenance, and protection of environmental values. SB-34's funding level of \$12 million per year, however, is less than that necessary to properly upgrade all Delta levees that require strengthening. The U.S. Army Corps of Engineers

(Corps) in 1982 estimated that it would cost \$1 billion to rehabilitate levees on 53 Delta islands. However, recent non-project levee improvements have been made at costs that indicate this figure could be decreased by 25% or more through the use of innovative engineering techniques. While many individuals involved in the SB-34 program believe that a comprehensive cost sharing plan needs to be implemented that will include all beneficiaries of levee protection, others are wary of too much centralization.

SB-34 also funds mitigation programs. To date, over \$3 million has been provided to the Department of Fish and Game (DFG) to mitigate impacts to habitat. However, controversy over implementation and management of SB-34 programs meant to supplement local projects to improve levee conditions has stymied efforts to move forward as expeditiously as many would like. Discussions are ongoing to resolve areas of contention between state agencies and local reclamation districts.

## **HISTORY OF DELTA LEVEES**

Delta reclamation began in the early 1850s. In 1861 the State passed the Reclamation District Act and in 1868 turned over responsibility for reclamation to local agencies and landowners.

Hydraulic mining during this era (halted by court decree in 1884) exacerbated Delta flood control problems as the debris washed down out of the mountains and reduced channel capacity. Also exacerbating this situation was the fact that as the Delta became more channelized and flood plains were protected, flood stages rose, necessitating still higher levees.

In 1893, the Corps was given federal jurisdiction over flood control. Today, the Corps manages a comprehensive program, the Sacramento River Flood Control Project (SRFCP), which focuses on levee improvement and maintenance.

The Corps is responsible for "project levees" constructed as part of the SRFCP, located mostly along the Sacramento and San Joaquin rivers and maintained to relatively high Corps standards. Nonproject levees (which comprise about 75% of all Delta levees) were constructed piecemeal by land owners and local reclamation districts and are maintained to varying degrees, although generally to a lower standard than those maintained by the Corps.

Flooding in each year from 1980 through 1983 and again in 1986 illustrated the vulnerability of nonproject levees and caused an estimated \$100 million in damage to the levee system, of which \$65 million was paid for by the Federal Emergency Management Agency (FEMA).

As a condition of future disaster relief, FEMA has imposed a minimum standard requirement for improvement of nonproject levees. This standard is contained in the state's

Hazard Mitigation Plan (HMP), prepared in 1983 and updated in 1986.

The state's primary responsibilities under the HMP are providing continued financial assistance to local reclamation districts (this was done through SB-34) and carrying out an annual inspection program. As indicated above, under the HMP local districts had to upgrade their levees to a specified standard. These improvements were scheduled to be completed by September 1991. As of November 1991, however, although most districts have made some progress toward satisfying the HMP, only four of forty-seven inspected districts complied with the minimum criteria.

Local reclamation districts point to delays in receiving state and federal disaster relief, as well as DFG policy requiring stream bed alteration agreements for work performed on the waterside of nonproject levees, as obstacles to meeting implementation schedules. An agreement is in process to allow a time extension in the HMP so that FEMA can evaluate progress on a district-by-district basis.

A key contributor to levee problems in non-mineral soil areas is subsidence, the lowering of the interior land level primarily as a consequence of microbial decomposition, topsoil erosion and oxidation of the islands' peat soils. Subsidence in the Delta has historically occurred at rates that are among the highest in the world. Levees which were originally built 2 or 3 feet above ground elevation, must now be maintained, in many cases, at heights of over 20 feet above the adjacent ground as a result of interior island subsidence.

Peat soil under levee foundations, subsidence and the use of sand in the construction of levees, are the primary factors that contribute to levee instability today.

## **BENEFITS DELTA LEVEES PROTECT**

Levees not only provide direct flood control protection for Delta lands and highways, railroads, natural gas fields, utilities, major aqueducts, homes and marinas, but they also provide indirect benefits to wildlife, Delta agriculture, water quality and recreation.

If the levees were not maintained and islands were allowed to flood, there would be a significant loss of habitat for land based wildlife species, including important wintering waterfowl habitat. This loss would create marginal habitat for aquatic species which would then inhabit the flooded islands.

Levees also provide riparian habitat for wildlife. While problematic for inspection and maintenance of the levees, riparian vegetation contributes to the shading of near shore (i.e. near levee) areas which are important habitat areas within the Estuary ecosystem.

Without the levees, Delta islands would not exist and obviously could not be cultivated. This would be a loss of over a half-million acres of agricultural lands and a half-

billion dollars of annual gross income from agricultural and related activities. Also, channels between tracts and maintained by the levees provide farmers with access to a ready source of irrigation water for their crops.

By maintaining the integrity of Delta channels, levees serve to protect the flow of water from the north of the Delta to the south and toward the pumps of the federal Central Valley Project and State Water Project. The present water transfer capacity of the Delta to move water is not as good as it might be, but it is generally considered to better than if there were no levees at all.

Western Delta islands serve as "barriers" that help stem the tide of salt water intrusion into the interior Delta. This is important for maintaining adequate water quality for beneficial uses served by the Delta, including fishery resources, recreation, in-Delta agricultural use and the quality of water exports among others.

The Delta is one of California's major recreational areas. It not only serves local and regional residents but it is also recreational destination for boaters from throughout California. The Delta's 50,000 acres of meandering and interwoven waterways serve over 12 million recreational user days annually. Recreational uses include fishing, water sports, houseboating, hunting, etc.

## **DELTA LEVEE FAILURE MECHANISMS**

Levee failures can be categorized principally by the major type of failure (stability, overtopping, seepage/erosion) and then by contributing factors (cracks/fractures, encroachments, deformation, sink holes, burrows, poor foundations). Subsidence, of the island interior and the levee itself, is another factor that must always be addressed when seeking to maintain levee stability. Seismic activity is also considered to be a probable failure mechanism. However, there is still only minimal understanding of how seismic events actually affect levee stability and what the impacts of a major quake would be.

### **Subsidence**

Subsidence, or lowering of the land surface, results primarily from peat soil being converted into a gas. Many Delta islands are composed of peat soils which decompose when exposed to oxygen and higher temperatures, a circumstance that is accelerated by agricultural activity. Mineral soils underlie the southern and eastern islands of the Delta and so they are not subject to the severe subsidence problems of the islands composed of peat soils. Another type of subsidence can occur when groundwater or natural gas is withdrawn. This so-called "deep" subsidence has little significance compared to "shallow" subsidence associated with soil erosion and oxidation. Controlling subsidence should be a significant element of any Delta flood

control plan.

### Stability

Factors affecting stability include size, shape, composition of foundation materials, strength, deformability and water pressure. While east Delta levees are generally supported by foundation materials composed of clay, silt, and sand, western Delta levees are primarily resting on peat with some alluvial clay, bay mud, sand and silt. While inorganic materials provide adequate foundations, uncompressed peat is highly deformable and unstable.

### Overtopping

Overtopping failure occurs when the crest of a levee is lower than the water level. Overtopping can occur not only as a result of the presence of flood flows, but also as a consequence of high tides and wind. Overtopping is of particular concern in the north and west Delta.

### Subsurface Seepage Erosion

Water seeping through or beneath levees contributes to erosion problems and a levee subject to such seepage may wash away from the inside out. Sandy levees are especially susceptible to seepage erosion and the resulting formation of "pipes" (large voids). Uncontrolled vegetation on levees can cause and shield piping from prompt discovery.

### Seismic Activity

Although preliminary studies have been completed in recent years, they have been inconclusive because of the lack of information regarding levees and their foundations, and uncertainty about the capabilities of organic soils beneath the levees to either amplify or attenuate ground motions triggered by earthquakes. Still, because levees are comprised of uncompacted sands, silts, clays, and organic soils, there is concern that they would be susceptible to liquefaction and damage during moderate to strong earthquake shaking.

## **FAILURE MODES**

### Cracks and Fractures

This mode is a particular problem for deformable levees built upon peaty foundations, as cracking will occur at load levels significantly below those required to cause a complete stability failure. While cracks do pose a stability problem, they pose a greater danger by providing shorter, unobstructed pathways for piping to occur.

### Encroachments

Encroachment of structures onto levee slopes may reduce the level of protection provided by the levee system and also make levee inspection, maintenance and improvements more difficult. Bethel Island and Hotchkiss Tract have many encroaching structures which were built before a setback regulation was adopted in 1989. Encroachment control plans are currently under development on other islands.

### Erosion

Levee waterside slopes are subject to varying erosional effects from channel flows, tidal action (which can cause water levels in some channels to vary by as much as 4 feet daily), wind-generated waves, and boat wakes. To counter erosion, riprap (rock) may be placed on the levee or a berm may be placed as a buffer in front of the levee to dissipate the water-borne energy before it reaches the levee itself.

Although vegetation can contribute to piping problems, it is generally desirable as a tool in controlling erosion. However, continual wave action at normal water levels frequently undercuts vegetation at the waterline, and can lead to progressive caving and erosion of the levee slope.

### Deformation

Levee foundations composed of peat or other soft organic soils are analogous to toothpaste. If enough pressure is placed upon them, the soils may squeeze out as they migrate to the path of least resistance. Placing heavy berms at the land side toe of the levee has been an effective method of "capping" the soft soils and preventing deformation.

### Seepage

Because interior land levels in many areas are so far below channel water levels outside the levees, seepage is a continual problem that contributes to instability in the low lying islands of the central and western Delta.

### Sinkholes

Sinkholes are depressions in the land side of the levee that are typically wet or filled with water. These sinkholes are symptomatic of erosion problems, specifically piping and deformation, and are usually found near levees overlying peat soils. Surface filling is the most effective corrective measure to mend sinkholes.

### Rodent Burrows

Rodent burrows increase the potential for piping problems to develop. Often, dense vegetation on levee slopes makes it difficult and impractical (but not impossible) to detect burrows.

## **LEVEE DESIGN**

Levee conditions in the Delta are unique in that unlike most locations where levees are built to protect land which is at a level above normal water levels, Delta levees protect lands which are far below the water level. Consequently, while levees in other regions generally need to be able to sustain pressures on an intermittent basis, Delta levees are really earthen dams which must function as continuous water barriers. Thus, Delta levees must remain fully functional during any improvements or repairs.

There are six main components of levee design: levee material, levee height, slope and foundation stability, seepage control, deformation control and erosion control.

## **LEVEE MATERIAL**

The Corps recently determined that it would take approximately 55 million cubic yards of material to rehabilitate substandard Delta levees. Because of the general scarcity of suitable soils within the Delta, most of that material would have to be imported.

The most accessible source of fill material is dredge spoils and sediment from Delta channels. However, removing material from the waterside toe of levees can cause stability and seepage problems. In addition, it is becoming increasingly difficult to remove channel material as a consequence of federal and state endangered species act restrictions on dredging operations.

Another potential source of levee fill material is land that may be borrowed when creating new wildlife habitat areas. For example, habitat plans under development for 500 acres of Department of Water Resources (DWR) land in the north Delta may provide several hundred thousand cubic yards of material.

Sand deposits on some islands are also a source of fill material.

### Long-Term Management Strategy (LTMS)

The LTMS is a program to prepare plans to manage dredging and the disposal of dredge spoils from the Bay over the next 50 years. The key participants in the program are the Corps, the U.S. Environmental Protection Agency, the San Francisco Regional Water Quality Control Board (SFRWQCB), and the San Francisco Bay Conservation and Development Commission.

Dredging in the Bay creates an annual disposal requirement of approximately 8 million cubic yards of material.

While some have suggested using those spoils to upgrade Delta levees, there are significant concerns regarding the possibility of water quality impacts (both salinity and pollutants). DWR, working with the Corps and the SFRWQCB, has been conducting demonstration projects to determine the viability of using Bay dredge material on Delta levees. In 1990, 1,600 cubic yards of dredge sediments from Suisun Slough was used to build a land side berm. After two years of monitoring, no adverse impact was detected on soils or water quality. In 1992, 50,000 CYs of sandy material from Suisun Bay was placed on Twitchell Island. Monitoring has not identified any significant salinity impacts.

### **LEVEE FUNDING**

In conjunction with funds from local landowners and reclamation districts, the Federal Emergency Management Agency (FEMA) has provided significant revenues for rehabilitation of levees after breaches have occurred.

Today, non-project levee enhancement is funded through the Delta Flood Protection Act of 1988 (SB-34). SB-34 authorized \$12 million annually through 1998-99, with the money to be split between supplementing local revenues and funding special levee projects in the western Delta and flood protection for Walnut Grove and Thornton. Appropriations to the SB-34 programs in the past two years have been substantially less than the authorized \$12 million per year, although the intended \$12 million was provided this year.

The cost of rehabilitating or raising the level of protection of a levee ranges from \$1.5 million to \$4 million a mile, depending upon the condition of the levee and its location. Because local landowners and reclamation districts cannot raise sufficient funds themselves, and SB-34 monies are also not of the magnitude needed to alleviate the entire problem, many people knowledgeable in Delta levee issues believe that a comprehensive cost sharing

arrangement amongst all benefiting parties needs to be established to equitably satisfy their needs. Others, however, do not wish to see a centralized system with such control over what is seen as a local issue.

## COMMENTS AND PERSPECTIVES OF PEER REVIEWERS

Reclamation District #548 in Lodi offered some recommendations: (1) long term cost sharing arrangements extending beyond the year 2000 should be implemented by the Legislature; (2) the Legislature should create an emergency fund; (3) the Legislature should set a 5 mph boat speed limit in specified areas of the Delta; and, (4) State agencies should implement plans to preserve channel islands and enhance habitat on them. A concern was also raised that without State and/or federal assistance, levees protecting small islands will not be repaired as local residents cannot afford to do so on their own. The proposed emergency fund would be in place for this purpose.

The California Central Valley Flood Control Association cautioned that comparisons of 1982 Corps estimates of levee repair costs to costs associated with recent levee repair work might be misleading as the Corps' estimates included recreation and fish and wildlife enhancement in addition to basic structural rehabilitation.

The State Reclamation Board (Board) commented that it is responsible under agreements with the Corps for operation and maintenance of Project levees. There are currently about 17 miles of federal levees within the Delta which are in need of repair. The Board, the Corps, and affected reclamation districts will be cost-sharing efforts to repair these levees.

The Seismic Safety Commission cautioned against interpreting the briefing paper as implying that earthquakes are not a concern as there is evidence that seismic activity does impact the integrity of the levees even though, historically, catastrophic failure has not been attributed to seismic events.

The Corps commented that it is important to distinguish between environmental mitigation and outright habitat creation. Additionally, the Corps notes that a great deal of work has been done to improve Delta levees since 1982.

Reclamation District #2026, managing Webb Tract, commented that the briefing paper may give an overly pessimistic impression in that far less than half of the 550,000+ acres in the Delta which are protected by levees is threatened by significant soft soil problems and subsidence. The majority of the islands are composed of mineral soils and as such are not subject to the same degree of levee problems as those in peat soil areas. Moreover, the District believes that management practices in the entire Delta need not be developed on the worst-case basis.

The East Bay Municipal Utility District (EBMUD) suggested that liquefaction from seismic forces be added to the list of levee failure mechanisms. Also, EBMUD emphasized that three of EBMUD's Mokelumne Aqueduct pipelines cross the Delta in areas which make them vulnerable to damage from levee failures caused by seismic activity or flooding. EBMUD also communicated that it has just completed an Aqueduct Security Study and has begun an Aqueduct Upgrade Project.

The Delta Protection Commission's Executive Director highlighted the apparent conflict between protecting the habitat value of the levees and the inspection, maintenance and rehabilitation problems associated with wildlife and vegetation.

The Central Delta Water Agency commented that levee alignment issues need to be better understood. Also, it needed to be noted that significant funding provided by the State's Natural Disaster Assistance Act (over \$26 million from 1980-1986) for emergency levee repair was critical to receiving \$65 million in FEMA assistance.

## **DELTA LEVEE REPAIR AND MAINTENANCE ISSUES**

### **INTRODUCTION**

With respect to levee and channel maintenance in the Delta, there are inherent conflicts between retaining and restoring fish and wildlife habitat on levees and maintaining those levees for flood protection. Implementation of the Delta Flood Protection Act of 1988 (SB-34) has been at the center of this debate. Included in this briefing report is a paper describing some of the issues pertaining to SB-34 programs, along with an appendix reviewing some of the fish and wildlife values associated with and protected by the Delta's levee and channel system.

Although the SB-34 discussion focuses mainly on "non-project" levees, some of the concerns raised are similarly applicable to "project" levees.

Non-project levees are maintained, repaired and upgraded by local reclamation districts in accordance with the State's Flood Hazard Mitigation Plan (FHMP) for the Delta. Portions of the costs for implementation of the FHMP are potentially reimbursable through the SB-34 program (up to 75% for maintenance and rehabilitation and up to 100% for habitat mitigation work). Project levees are maintained according to federal regulatory standards.

Traditionally, levees were considered almost exclusively as a means to protect farm land, homes, and other public development including railroads and highways. In addition to those considerations, fish and wildlife habitat issues have in recent years received increased importance. With this shift a conflict among uses and purposes has arisen, as maintaining and developing habitat values on the levees is believed by many to threaten the levees' structural integrity or, at minimum, impair routine inspection, maintenance and repair. Still, despite disagreement among the players over emphasis and priorities, there is general agreement as to the benefits of protecting Delta islands and their important habitat values.

### **LEVEE AND CHANNEL MAINTENANCE ISSUES**

Dredging may result in temporary adverse water quality impacts, which can also affect aquatic resources in the impacted area. These concerns, particularly with respect to enforcement of the federal Endangered Species Act have limited dredging activities in the Delta to a 60 day period in the summer when fishery impacts are minimized. As long as the dredging window is so restricted, there is a risk that fill material from dredging will not be available to maintain and restore levees.

## **LEVEE MAINTENANCE ACTIVITIES**

Installation of revetments and riprap typically requires removal of vegetation which often results in conflicts with maintenance of both aquatic and terrestrial habitat. Many levee maintenance managers believe that extensive vegetation on the levees can present a hazard to flood protection capabilities. Fish and wildlife managers emphasize the importance of maintaining levee vegetation for habitat values. The perception of the impacts, both to wildlife and habitat and to the levees, tends to differ, depending on the focus or responsibility of the individual or agency. As expected, agencies responsible for flood protection place a higher priority on that issue while fish and wildlife agencies place a higher priority on their responsibility to maintain fish and wildlife resources. In addition to the difference of opinion as to the nature of the problem, there are also disagreements over the appropriate maintenance methods.

## **CURRENT INITIATIVES TO ADDRESS THE LEVEE CONCERNS**

Programs are currently underway at the State and local level to address the need to protect habitat values while maintaining flood protection. Such programs include levee maintenance and some dredging activities.

Vegetation guidelines are being developed for levee habitat enhancement and mitigation.

Also, two demonstration slope protection projects have been implemented as part of the SB-34 program using materials other than riprap which allow vegetation regrowth without erosion. Many districts feel these relatively expensive alternatives are unnecessary as they believe that riparian vegetation can effectively reestablish itself on riprap.

Fish exclusion devices are being studied for use at sites where clamshell dredging is occurring. Also, fish distribution studies are underway to try to assess where dredging might take place at other times of the year without harm to aquatic species of concern.

## **INTERAGENCY COORDINATION**

There exists a Delta Levee and Habitat Advisory Committee within the Resources Agency that is working to (1) Streamline permits for levee work in the Delta; (2) Explore the utility of Habitat Conservation Plans; and (3) Provide guidance on Habitat Mitigation Plans. The Resources Agency has also had recent discussions with the Corps and the USFWS to secure a General Permit for SB-34 projects.

The California Department of Fish and Game will soon release its "Mitigation Guidance Document," which is a handbook for levee districts and landowners to assist in the

development of habitat mitigation plans. One of the key proposals endorsed is the use of mitigation "banks" to enhance overall habitat quality and diversity.

## **ISSUES AND IMPLEMENTATION OF THE SB-34 PROGRAM**

SB-34 was enacted to facilitate and fund levee maintenance, with specific emphasis on New Hope Tract and eight key west Delta islands. SB-34 also focused on protecting and enhancing the fish, plant and wildlife resources of the Delta. Most significantly, SB-34 required that projects receiving funding arising from the Act would not result in a net long-term loss of riparian, fisheries or wildlife habitat, with a DFG finding to that effect to be issued before funds are disbursed.

Initially, there were disputes around regulatory jurisdictional issues and also differences of opinion concerning the intent of the legislation. Follow-up legislation, SB-1065, provided specific guidance and consequently the reclamation districts, assisted by DWR and DFG have made progress towards meeting the habitat conservation goals originally set forth in SB-34.

While resolution of the conflict between competing priorities of flood protection and habitat protection have held center stage, funding is a growing concern. Although originally set at \$12 million per year through 1997, funding was less than that in 1991-92 and was only \$2 million in 1992-93. Additionally, \$3 million specifically set aside for DFG mitigation programs has not been expended and the monies will revert to the general fund on June 30, 1994. There is some concern that this funding opportunity will be lost because an acceptable project cannot be decided upon.

Without additional legislation, SB-34 funding authorizations will expire in 1997 and full funding for levee maintenance will revert back to local reclamation districts.

## **CONCLUSION**

Though plagued by early conflicts between flood protection and habitat values, recent history suggests that the SB-34 program is becoming more effective. Continued focus on minimizing environmental impacts while developing innovative techniques to restore and maintain the structural integrity of the levees remains the key to successful programs.

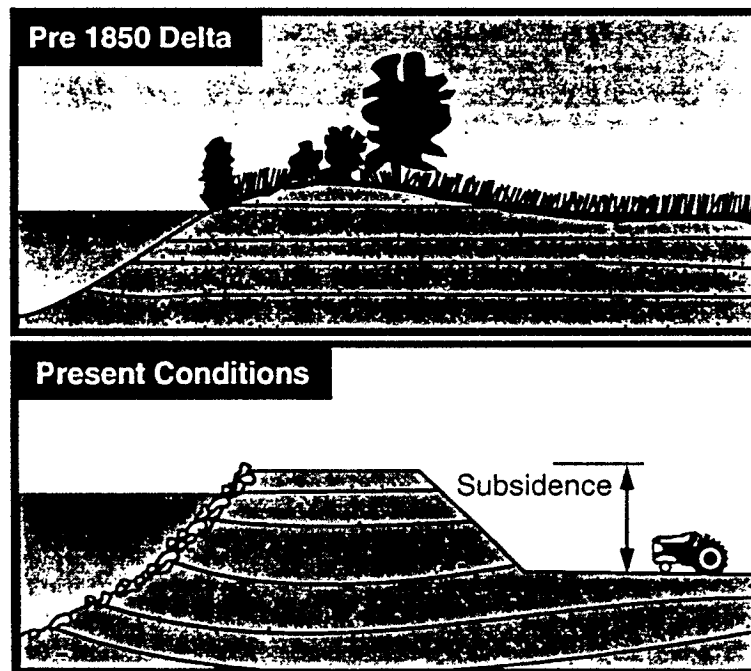
# **DELTA LEVEE AND CHANNEL MANAGEMENT ISSUES**

## **GENERAL ISSUES RELATED TO THE PHYSICAL INTEGRITY OF DELTA LEVEES**

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# DELTA LEVEES



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# DELTA LEVEES

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# EXECUTIVE SUMMARY

The Sacramento-San Joaquin Delta is one of California's most valuable, irreplaceable resources and without adequate levees, the Delta as we know it today will be lost. The levees serve many diverse needs. They protect valuable wildlife habitat, farms, homes, urban areas, recreational developments, highways and railroads, natural gas fields, utility lines, major aqueducts, and other public developments. The levees are also critical to protecting Delta water quality and serve a significant function in the State's water transfer system. In the Delta Flood Protection Act of 1988 (SB 34), the Legislature declared "...that the delta is endowed with many invaluable and unique resources and that these resources are of major statewide significance."

Since reclamation of the Delta began in the 1800's, the levees have increased from under 5 feet to over 25 feet in height. Due to subsidence of the island interiors, it was necessary to continually add material to hold back the adjoining rivers and sloughs. Since many of the levees were built piecemeal over many decades with little understanding of the engineering challenges posed by the Delta's geology and the impacts of long-term subsidence, there has been an ongoing concern over the performance of these levees.

Levee conditions in the Delta are quite different than those in many other locations, where land elevations are above normal water levels. Water forces then act on levees only during periods of high water or flooding. In the Delta, land elevations are generally much lower than waterway elevations. Because of this difference, the levees function more as earthen dams which act as continuous water barriers. This difference between many Delta levees and levees in other areas has important implications regarding levee design and reconstruction. For example, most of the Delta levees have to remain fully functional during any improvements or rehabilitation.

Levee failures continue to be one of the Delta's primary problems. Levee failures in the Delta are due to several factors which include: instability, overtopping, and seepage. To gain a better understanding of the problems facing the Delta, DWR has financed engineering investigations such as a recently completed seismic analysis of the Delta levees (see the adjoining report: *Review of Seismic Stability Issues for Sacramento-San Joaquin Delta Levees*). These investigations along with levee improvement projects performed under SB 34 have demonstrated that many difficult Delta levee problems are solvable. SB 34 has provided the necessary focus for coordinated levee engineering investigations and improvement projects that have advanced the state of the art of levee design. These efforts have demonstrated that levees can be engineered to alleviate the unfavorable conditions which continue to threaten this water hub of unique economic and natural value. SB 34 programs have also significantly advanced the understanding of Delta subsidence, its causes, and the importance of integrating subsidence control with levee improvements.

An important goal of SB 34 is the completion of levee improvements in a manner which is conscious of the habitat value of the levees. All levee improvement projects must be implemented in a way which allows no net long term loss of habitat. For example, levee upgrade work on Twitchell Island created a new 4 acre habitat to replace 3 acres of levee slope habitat that was disturbed while improvements were being made. Through the SB 34 program, over \$3,000,000 has been provided to the Department of Fish and Game for habitat creation.

While maintenance and improvement work can affect habitat present on a levee, such work is vital to the protection of the island itself and the habitat existing on the island. The importance of the Delta as habitat can be seen in its

increased use by waterfowl. With the dwindling wetland habitat throughout the state, the winter use by Delta waterfowl has increased from 0.5 million birds 20 years ago to about 1.5 million today.

With regard to Delta levee improvement costs, the United States Army Corps of Engineers (Corps) in 1982 estimated that almost \$1 billion would be needed to rehabilitate levees on 53 Delta islands. Costs for some of the worst levees in the western Delta ranged from \$2-4 million/mile. However, improvements made in 1992 and 1993 on extremely fragile levees in the western Delta have been completed using an innovative design for less than \$1.5 million per mile. Even after accounting for recreation and maintenance, these costs are significantly less than the estimates made over 10 years ago to repair the same levees to essentially the same standards. Use of new designs, extensive monitoring, and economical borrow sources are all factors which need to be considered in developing realistic future costs.

Clearly, however, rehabilitation costs

exceed the financial resources of most Delta landowners. Funding through SB 34 has provided for significant levee improvements, but is insufficient to properly rehabilitate all Delta levees. Therefore, a comprehensive cost sharing arrangement needs to be established which will address benefits and equitable cost sharing among all the beneficiaries. Cost sharing arrangements similar to those being forged with the Long Term Management Strategy (LTMS) program to provide economical sources of levee material will help to meet this objective.

Significant DWR activities focus on protecting the Delta both through emergency work and long term planning. SB 34 allows the Department to mobilize forces to take necessary immediate action for threatened levee sites as well as provide long term improvement projects. The long term improvement projects that DWR has sponsored address the specific problems of each levee system in a flexible manner. While this approach requires a larger investment for levee improvements, the long term benefits are well worth the cost.

# HISTORY OF DELTA LEVEES

The process of reclaiming the lands of the Delta began in the California gold rush era of the early 1850s. The population influx created a demand for food, which in combination with fertile Delta soils, convenient water supply, and shallow draft shipping to Central California markets created an incentive to reclaim and farm the Delta. The Federal Swamp and Overflow Act of 1850 provided for title transfer of wetlands from the Federal Government to the states and in 1861 the California Legislature passed the Reclamation District Act, allowing the formation of local government agencies for the purpose of providing mutual drainage and flood control benefits to the landowners within the District boundaries. However, it was not until 1868 when the state turned over responsibility for reclamation to the local agencies and landowners that large-scale reclamation was spurred.

Settlers first constructed low barriers of earth (see Figure 1) on the higher natural levees formed by deposits during previous floods. These low barriers, called "shoestring levees," were built primarily to keep tilled soil from washing away. Settlers rarely tried to prevent high tides from easing water over the lower portions of their land.

The first levees were built with two purposes in mind. Levees built around the islands of the central Delta were intended primarily to exclude tidal water from the tracts underlain by peat; those built along the sedimentary banks of the rivers were also expected to protect the reclaimed land from high flood stages. These levees, built by immigrant Chinese laborers, were constructed by piling material on the river banks when high water threatened to overtop the levee. This produced levees that were narrow and steep-sloped with minimal freeboard. These practices resulted in levees that had to be maintained continually to combat settling and subsidence.

As reclamation continued, owners of the new land found that as more and more land was leveed off, flood stages rose, thus necessitating higher levees in order to have the same protection. As land was developed through levee construction in the Valley, the gold mining industry was developing hydraulic mining technology in the foothills and mountains to the east of the Sacramento Valley. Hydraulic mining generated a tremendous volume of debris which was washed downstream and settled in Valley streambeds. This tremendous load of new sediment exacerbated flood control problems due to

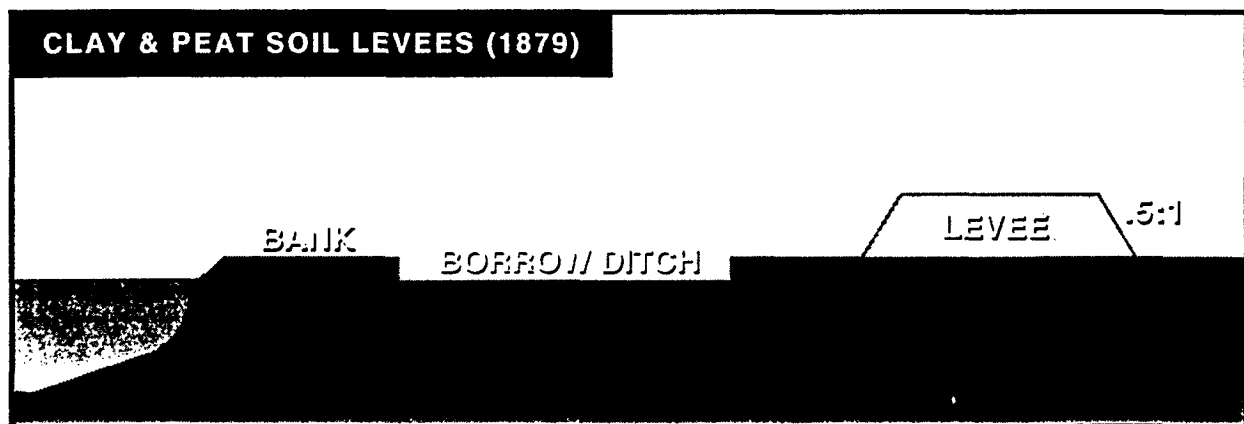


Figure 1: Cross-section of levees on sedimentary banks, 1879 (from Thompson, 1982)

# LEVEE STANDARDS

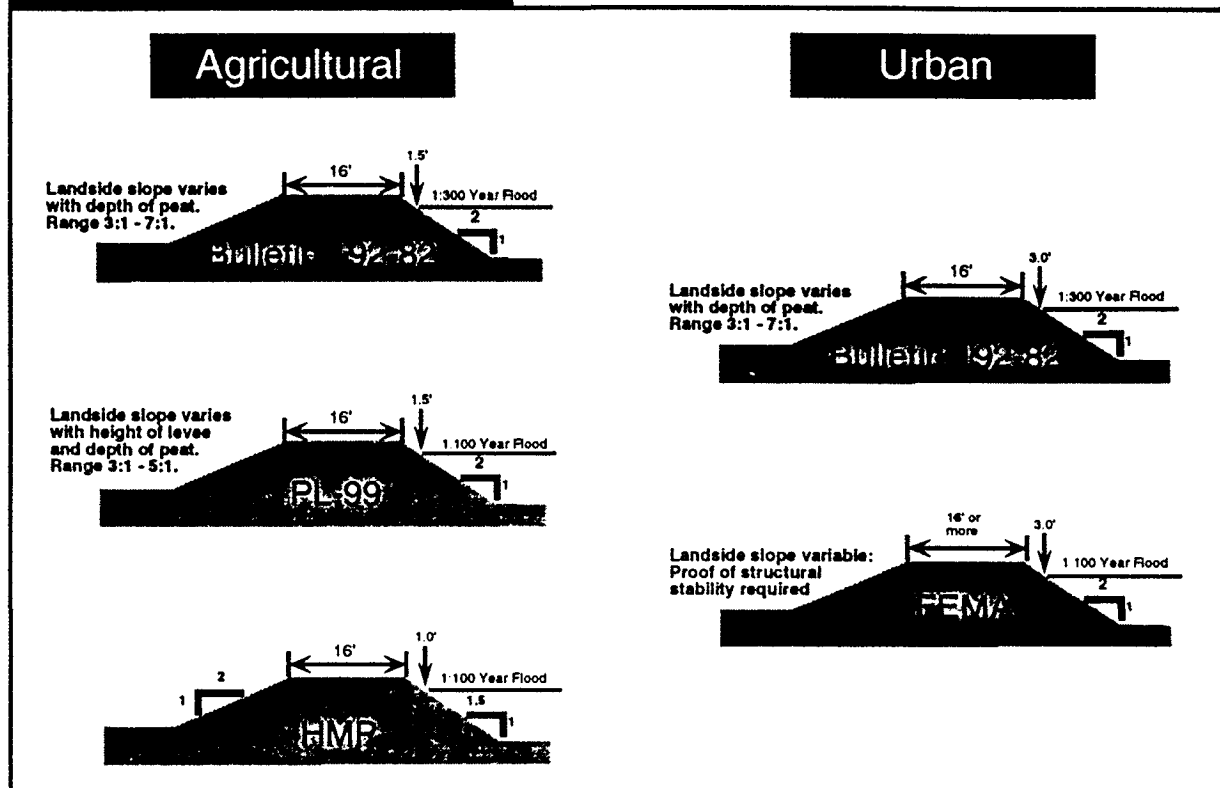


Figure 2: Levee standards (from DWR, 1990)

reduced channel capacities and also interfered with navigation.

Although hydraulic mining was stopped by court decree in 1884, the existing sediment load was still an ongoing problem. Individual landowners and local reclamation districts found themselves in competition, not only with the river, but with each other, in a battle to build higher levees so that when the inevitable flood came, it would destroy someone else's land. Clearly, a more coordinated approach to flood control was necessary.

This coordination was ultimately provided by the Corps. Beginning in 1893, with the Caminetti Act, the Corps began an involvement in flood control and navigation improvement which continues today. A major outcome of federal involvement in Sacramento Valley flood control problems is the Sacramento River Flood Control Project (SRFCP) in which a comprehensive program for levee improvement was undertaken.

Those levees that are part of the SRFCP are known as "project levees." Mostly found along the Sacramento and San Joaquin rivers, they are maintained to Corps standards and generally provide dependable protection. Nonproject or local levees (75 percent of Delta levees) are those constructed and maintained to varying degrees by island landowners or local reclamation districts. Most of these levees have not been brought up to federal project standards and are less stable, increasing their vulnerability to failure. The continuing precarious condition of local levees has been demonstrated several times since 1980. In particular, severe flooding in the Delta in each season from 1980 through 1983 and again in 1986 caused an estimated \$100,000,000 in damage to the levee system. The federal disaster assistance program, administered by the Federal Emergency Management Agency (FEMA), provided reimbursement of approximately \$65,000,000 for levee damage.

Because of the large federal contribution

during this period and the prevalence of inadequate local levees that would still be at risk during high water, FEMA required that local levees be maintained and improved to a minimum standard as a condition of future disaster assistance. The criteria for the standard are defined in the State's Hazard Mitigation Plan.

The HMP was prepared after the flooding in 1983 and subsequently updated with essentially the same 1983 plan elements after the flooding in 1986. Continued financial assistance to local Delta levee districts and the setting up of an annual inspection program were primary state responsibilities listed in the latest HMP. Local districts' responsibilities included the adoption of the short-term HMP standard (see Figure 2) and the timely upgrading of their levees to that standard. As a prerequisite for receiving disaster aid after the 1986 flood, and in order to be eligible for future federal disaster assistance, the local districts agreed to complete upgrading their levees to the short-term HMP by September 1991. Passage of the Delta Protection Act of 1988 (SB34), committed the State to make funding available to local districts for completion of levee maintenance and rehabilitation objectives outlined in the HMP. The state also set up an annual local levee inspection program so that results of local districts' progress toward completion of the HMP could be reported to FEMA.

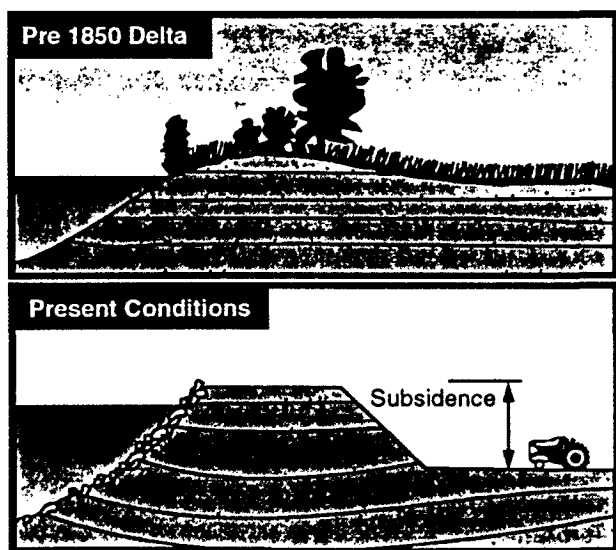


Figure 3: To offset subsidence, some of today's levees stand over 30 feet high.

Based on a November 1991 inspection, FEMA and the State Office of Emergency Services (OES) personnel asserted that although substantial progress had been made by most districts, only four of the forty-seven districts inspected complied with the minimum HMP criteria. Many districts have cited financial difficulties caused by delayed reimbursement of 1980's federal and state disaster assistance claims and lower than expected average levels of annual Subventions Program dollars as contributing factors for not meeting the September 1991 deadline.

Another reason cited for project delays was the policy instituted by the Department of Fish and Game to enforce streambed alteration agreements for work performed on the waterside of nonproject levees. Discussions between Local Districts, DWR, FEMA, and OES have begun to implement a proposed amendment to the FEMA/State HMP Agreement allowing districts more time to complete HMP requirements. In these discussions, FEMA has informed the districts that the September 1991 deadline will not be applied and that instead, with implementation of a proposed amendment to the FEMA/State Agreement, progress will be evaluated district by district.

In an effort to achieve better stewardship of wildlife resources on the Delta levees, DWR has developed an appendix to the proposed amendment to the FEMA/State HMP Agreement. The purpose of the appendix is to provide Delta reclamation districts, whose responsibility includes maintenance of local levees, with flexible guidance for levee vegetation management consistent with the requirements of the State's HMP.

## SUBSIDENCE

Subsidence has a significant impact on Delta levees because the hydraulic gradient through the landside toe of the levee increases as the toe elevation decreases. Prior to land reclamation in the late 1800's and early 1900's, the Delta (see Figure 3) was a freshwater tule and reed marsh. The Delta developed throughout a time of rising sea level due to melting ice sheets as the earth warmed from the last ice age. Over

the years, ground elevations in the Delta rose with the sea level through deposition of decayed plant material. The result was a layer of peat soil over a large part of the Delta. In some areas, this peat was more than 50 feet deep.

When this peat land was drained for farming, it dried out, warmed up, and began to oxidize. The loss of soil through oxidation has led to subsidence of the ground surface at a rate of up to 3 inches per year. In the central Delta, the land surface has subsided as much as 21 feet over time

and is now more than 15 feet below sea level. The Sacramento San Joaquin Delta has historical rates of subsidence that are among the highest observed in the world.

Since the water levels in Delta channels have changed relatively little in the last century, the levees that started out 2 or 3 feet above ground elevation must now be maintained, in many cases, over 20 feet high. Today, peat soil, subsidence and levees constructed of sands still remain the primary causes of levee distress.

# FLOOD CONTROL BENEFITS

The Sacramento-San Joaquin Delta is irreplaceable, and without adequate levees the Delta as we know it today will be lost. The levees serve many diverse needs. They protect valuable wildlife habitat, farms, homes, urban areas, recreational developments, highways and railroads, natural gas fields, utility lines, major aqueducts, and other public developments. The levees are also critical to protecting Delta water quality and serve a significant function in the State's water transfer system.

## **FISH AND WILDLIFE**

The Delta levees protect important wildlife habitat for numerous species of waterfowl and other wildlife. The diversity of Delta habitat supports:

- 230 species of birds,
- 45 species of mammals,
- 52 species of fish,
- 25 species of reptiles and amphibians,
- 150 species of flowering plants.

If the islands flood, the habitat on the island that supports many animal and plant species would be replaced by open water habitat to fish and other aquatic life. The land subsidence experienced throughout the Delta would create flooded areas that would be deep. These deep areas would not have the high phytoplankton production of older flooded regions, and would thus be of lower value to the fisheries. The net result of flooded islands would be the loss of significant habitat for land based species in exchange for marginal habitat for water based species.

A limiting factor for waterfowl on the Pacific Coast is the availability of wintering habitat in California. That habitat has dwindled from over 5 million acres of wetlands to about 450,000 acres. Winter use of the Delta by waterfowl has increased from about 0.5 million birds

20 years ago to about 1.5 million today. This is a substantial portion of the Pacific Flyway fall flight and is thought to result from two food factors: the salt-tolerant plants of the Suisun Marsh and the waste grain left after harvesting corn on the Delta islands. Subsequent flooding of these areas due to a levee failure would eliminate these food sources and, consequently, have damaging effects on waterfowl, birds, mammals reptiles, amphibians, and plants.

## **DELTA AGRICULTURE**

The predominant land use in the Delta is agriculture. Of 738,000 acres, more than 70 percent is in cultivation. Delta soils are good for many crops, and the channels between tracts provide a ready source of irrigation water. The annual gross income of agricultural activities exceeds \$500 million. The Delta levees provide protection for both the cultivated land and the quality of the irrigation water.

In addition to crops grown in the Delta, an even larger area of cropland is irrigated with water diverted from the Delta by the Central Valley Project (CVP) and the State Water Project (SWP). Most of this diverted irrigation water is used in the San Joaquin Valley to grow nearly every type of crop produced in California. The average annual area irrigated with CVP and SWP water in the San Joaquin Valley was about 2.2 million acres in 1980, requiring about 4.5 million acre-feet of water from the Delta. The estimated value of these crops was \$1.8 billion in 1980, not including the value of any crops grown outside the San Joaquin Valley.

## **WATER QUALITY**

The Delta is a vital link in the State's water supply. Degradation of the water supply by saline water (see Figure 4) could result from the failure of one or more Delta levees, making water unsuitable for use by about two-thirds of

## Salinity Gradient in Relation to Eight Western Delta Islands

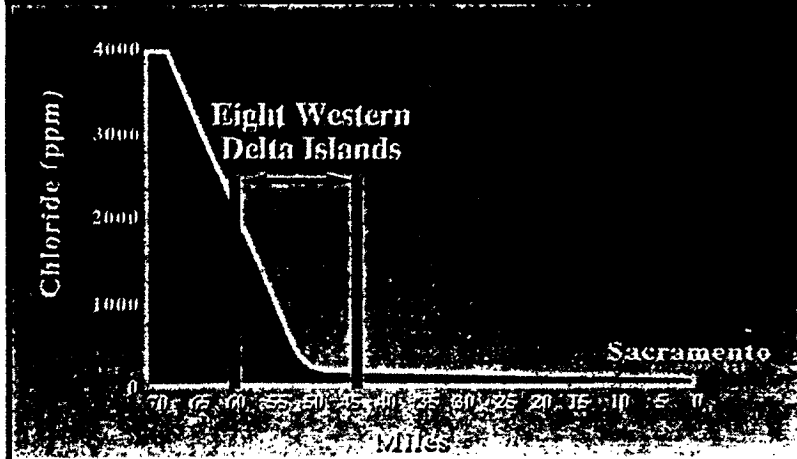


Figure 4: Salinity gradient in relation to the Western Delta Islands (from DWR, 1990)

California's residents. If a levee on one of the western Delta islands fails and the island floods and is not reclaimed, the following long-term problems exist:

- The area of the mixing zone increases;
- the rate of fresh and salt water mixing increases;
- the path for ocean salt water intrusion into the Delta decreases; and
- the amount of evaporation losses increases.

All these factors contribute to increased salinity intrusion and subsequent degradation of the water quality for all beneficial uses of Delta water.

As demonstrated in past flood events, significant short-term water quality impacts can occur even if a flooded island is reclaimed. California's recommended salt level for drinking water is 250 parts per million (ppm) chloride. However, during a previous island flooding under low-flow conditions, chloride levels reached 440 ppm at the Contra Costa Canal Intake, and several tons of additional salts were exported to users of water diverted from the Delta. Protecting the Delta's water quality is essential, not only because the Delta is the source of drinking water for more than 20 million people, but also because

the estuary is a unique and valuable resource.

## RECREATION

The Delta, because of its proximity to several large population centers, has become one of California's major recreational areas. The meandering and interwoven waterways provide 50,000 acres of protected waters for recreational activities that amount to over 12 million user days annually. Opportunities exist for fishing, boating, picnicking, camping, water sports, and sight-seeing. In the Delta there are:

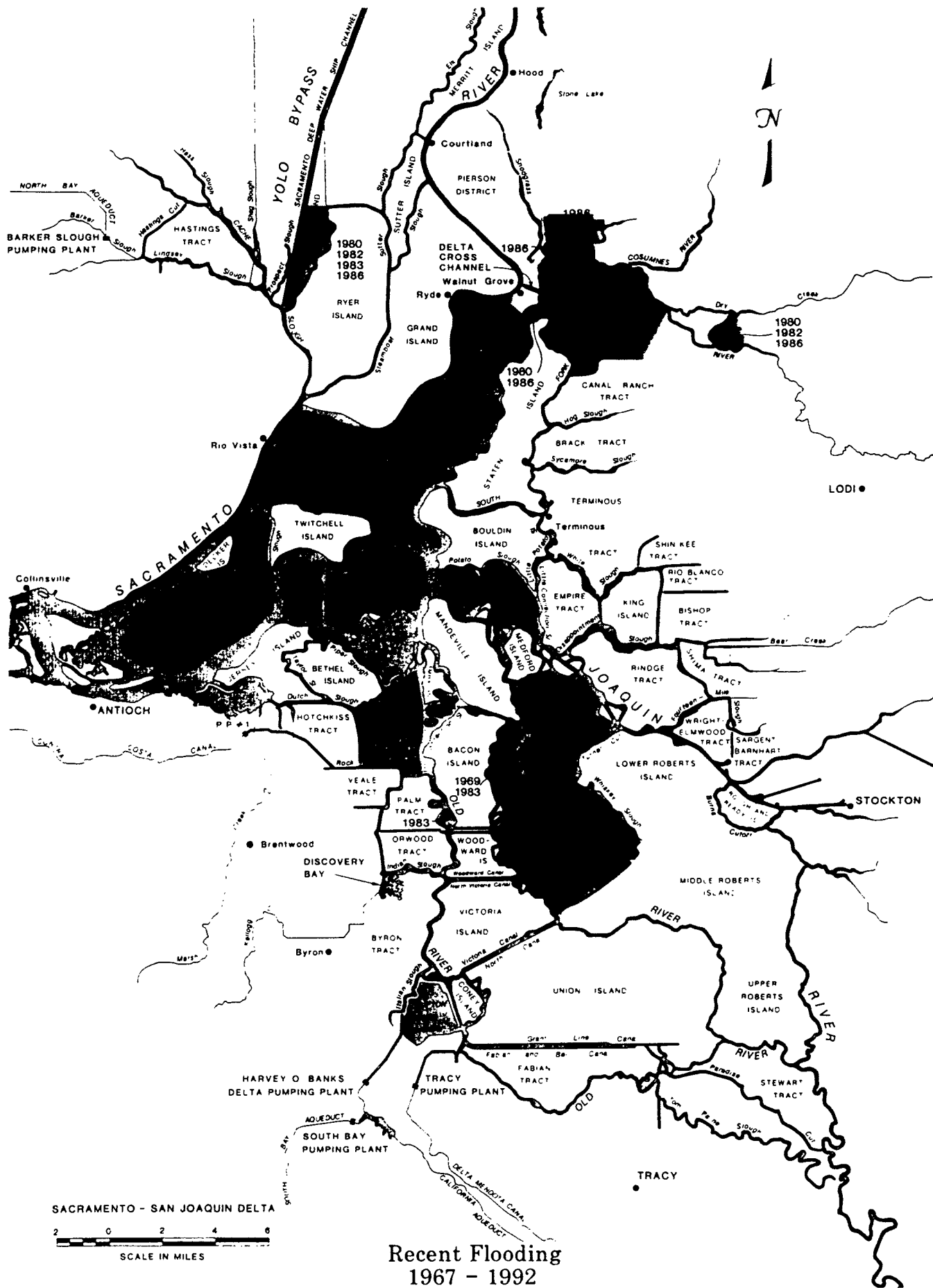
- 82,000 registered pleasure boats,
- 120 commercial recreation facilities,
- 20 public recreation facilities,
- 20 private recreation associations,
- 8500 berths, 120 docks, and
- 30 launch facilities.

The Delta would lose many of its attractive qualities if levees were to fail, creating inland seas.

## FLOOD PROTECTION

Flooding has been a major problem in the Delta since the first levees were constructed in the early 1850's. Approximately 100 levee failures have occurred in the Delta since 1900. About 35 of these failures have occurred since 1930. Before 1950 most of the failures were due to levee overtopping. The construction of upstream dams has now reduced the threat of this failure mechanism. However, failures due to levee instability and seepage are becoming more prevalent.

In the future if levees that fail are not repaired, large areas in the Delta could become open water surfaces like Franks Tract, Big Break, and Lower Sherman Island. In these cases, portions of the levees have mostly washed away, causing the flooded islands to become part of the open water estuary. Much of the destruction of



Recent Flooding  
1967 - 1992

Figure 5: Recent Flooding  
Delta Levees

these former levees was caused by wind-wave action on the unprotected interior levee slopes. Depending on the islands that flooded, there could be increased erosion from wind-driven waves and increased seepage on islands adjacent to these large open water areas. By letting flooded islands become part of the open water surfaces, adjacent islands could be placed at a higher risk of levee failure.

# LEVEE FAILURE MECHANISMS

Levee failures continue to be one of the Delta's primary problems. Levee failures in the Delta are due to several factors, including: instability, overtopping, and seepage. When a levee fails, the beneficial uses of the island and waterway are jeopardized as well as the lives of the people inhabiting the island. Major costs are also incurred to reinstate the levee and pump out the island. To understand what measures need to be taken to remedy levee problems, it is first necessary to understand the mechanisms that drive these levee failures.

## **FAILURE CATEGORIES**

Failures can be identified principally by the major category of failure (stability, overtopping or subsurface seepage erosion), then more specifically by contributing factors (subsidence, cracks and fractures, encroachments, erosion, deformation, seepage, sink holes, rodent burrows, and poor foundation conditions). One characteristic that aggravates failures is the contribution of subsidence or decrease in land-surface elevation.

### **Subsidence**

Subsidence is a significant factor in many of the central and western Delta levee failures, since it has caused many of the islands' interiors to lie substantially below sea level. Subsidence is due primarily to the loss of organic soil such as peat, a soil that contains more than 50 percent organic matter. Exposing peat to oxygen causes aerobic decomposition, a process whereby microbial organisms convert organic carbon solids to carbon dioxide and other gases. Activities which raise the soil temperature and reduce soil moisture greatly accelerate this process. This reaction occurs within the first few feet of soil and is referred to as shallow subsidence. Recent studies indicate as much as 50 pounds of carbon per acre are being lost to the atmosphere each

day. This carbon loss has a measured effect of lowering the land surface approximately 0.05 mm per day. Deep subsidence, shown by preliminary analysis to have little effect when compared to shallow subsidence, is caused by ground water withdrawal and a decline of natural gas pressure.

Land subsidence research for the Delta is continuing under a cooperative agreement between the United States Geological Survey and DWR. Currently the USGS is conducting a study on Twitchell Island to determine the rate at which the soil is losing carbon (carbon flux) under various land and water management practices. The working hypothesis of this research is that flooding and vegetative cover will cause the rate of oxidation to slow. Results of evaluating historical subsidence indicate the 1) subsidence is slowing over time and, 2) areal variability of subsidence rates are related to varying soil organic matter.

Continuing subsidence poses a major threat to the stability of the west Delta levees. Results of an analysis by the Corps indicates that there is likely to be two to three times the number of levee failures as a result of subsidence during the next 30 years, compared to the last 30 years. Efforts to control subsidence should be a significant part of any Delta flood control plan.

For example, construction of a trench in the western Delta provided a glimpse of future problems if subsidence is not controlled. Removing the peat soil caused numerous sand boils to develop in the bottom of a shallow trench. Boils like these, which can internally erode a levee, could become more common on the western islands if subsidence is not controlled.

### **Stability**

Factors which affect levee stability include size, shape, strength, deformability, and water pressure. For example, on Twitchell Is-

land, high, narrow levees made of weak soils over deformable peat foundations were among some of the most unstable levees in the Delta prior to improvement.

Levee foundation materials in the Delta vary. They include clay, silt, and sand in the east Delta and peat with some alluvial clay, bay mud, sand, and silt deposits in the west Delta. In general, the inorganic materials provide adequate foundation conditions, but uncompressed peat has an extremely low density and is highly deformable. Water pressure against and within the levees and the weight of the levee can cause this foundation material to compress and to displace laterally, resulting in a levee failure.

Differential foundation settlement may be another cause of stability failures, particularly where levees are founded on peat that abuts old, historic river channels that have been filled, or sloughs filled with clay and sand. The clay, silt, and sand-filled channels do not consolidate very much compared to the surrounding peat. Cracks may develop in the levee above the old channel sediment-peat contacts, encouraging subsurface seepage erosion called "piping". Although the actual causes of the levee failures have not been determined, both the 1980 failure of the Santa Fe Railroad embankment that separated Upper and Lower Jones Tracts and the 1982 failure of McDonald Island levee were near such old channels.

Levee failures are often preceded by a localized partial failure involving 200 to 1,000 feet of levee. Partial failure includes settlement of the levee and the formation of cracks and sinkholes in the landward levee slope. Unless repair is immediate, the condition may become worse until the levee fails completely.

### **Overtopping**

Overtopping failure occurs when the crest of a levee is lower than the water level. The combination of high tides, wind, and high discharges into the Delta contribute to overtopping and subsequent levee failure. While construction of upstream reservoirs since the middle 1940's has reduced the frequency of levee overtopping, overtopping remains a threat to the Delta islands,

and especially to islands of the North Delta..

On December 3, 1983, a section of levee on Bradford Island failed as a result of overtopping. On that day, many levees were suffering some overtopping and the chances of other levee failures throughout the Delta were imminent. Abnormally high tides coupled with high river discharges and high winds produced a dangerous situation. The threat could have been prevented by maintaining adequate levee freeboard by raising levees that had settled below critical elevations.

Soil logs from exploratory drill holes along the alignment of some levees show that peat in the foundations is now only about 60 percent of its original thickness. Efforts to control consolidation and deformation of these thick peat foundations can also successfully reduce the probability of future overtopping.

### **Subsurface Seepage Erosion**

Water seeping through or beneath levees may result in critical conditions as the soil erodes through the levee, creating large voids (pipes). These voids continue to grow and work their way backwards from the seepage discharge point. If piping is not properly controlled, levee failure may occur because the levee simply washes away from the inside out. The Thornton levee failure represents these types of failures and are characteristic of the sandy eastern Delta levees. Piping may be caused by any one of the following:

- burrowing rodents,
- loosely consolidated or sandy levee material,
- decaying tree roots,
- old pipes buried in the levee,
- settlement cracks,
- high water, or
- a narrow levee.

Vegetation allowed to grow uncontrolled and dense may become particularly hazardous. It can shield the true condition of a levee, preventing levee inspectors from spotting potential problems and correcting them in time. Also, during times of high water, vegetation can impede flood fighters from effectively combating leaks.

## FAILURE MODES

To provide adequate protection for the Delta islands, it is necessary to understand the characteristics and causes of levee failures. Engineering investigations for work on threatened levees have been instrumental in gaining this understanding. The failure modes can either be identified as continuous or transient in nature.

### Cracks and Fractures

Cracks and fractures in levees are often a common sign of levee distress, especially on deep peat islands found in the western Delta. The cracking phenomenon can be explained by considering the highly deformable nature of the peat soils present beneath and to the landside of levee embankments. The peat typically deforms considerably at loads significantly less than those required to cause a stability failure. This condition is most acute when fill is placed on peat that has not previously been loaded and which may be highly deformable. As the peat deforms and consolidates in response to the weight of the newly applied fill, it becomes less subject to deformation. For example, on Twitchell Island 4 feet of berm fill placed on virgin peat has settled to below the original ground elevation. Large settlements in the berm relative to the levee embankment caused 6-inch-wide cracks with almost a foot of vertical offset. While the cracks

pose a stability problem, they pose a greater danger by providing shorter, unobstructed pathways for piping to occur.

Another explanation for cracking is the lateral movements of the underlying peat, particularly beneath the levee's berms. These movements may be related to a lowering of the water table on the land side of the levee, since removing buoyancy has a net result similar to adding levee load. Reports of cracking of the landside slope of levees after times of drought are not uncommon and probably are frequently due to this cause.

Once cracked, the levee fill may tend to act as a series of adjacent blocks of soil on a soft base, and relative movements (e.g., as a heavy block settles and heaves up a lighter adjacent block) could be expected. Additional external loading could also trigger relative movements, which might explain the occurrence of significant cracking following periods of high tides or the placement of additional fill on the levee crown.

### Encroachments

Encroachments may reduce the level of protection provided by the levee system and also make levee maintenance and improvements more difficult. The performance of levees, which are critical during periods of high water, can be compromised by structural encroachments. Struc-

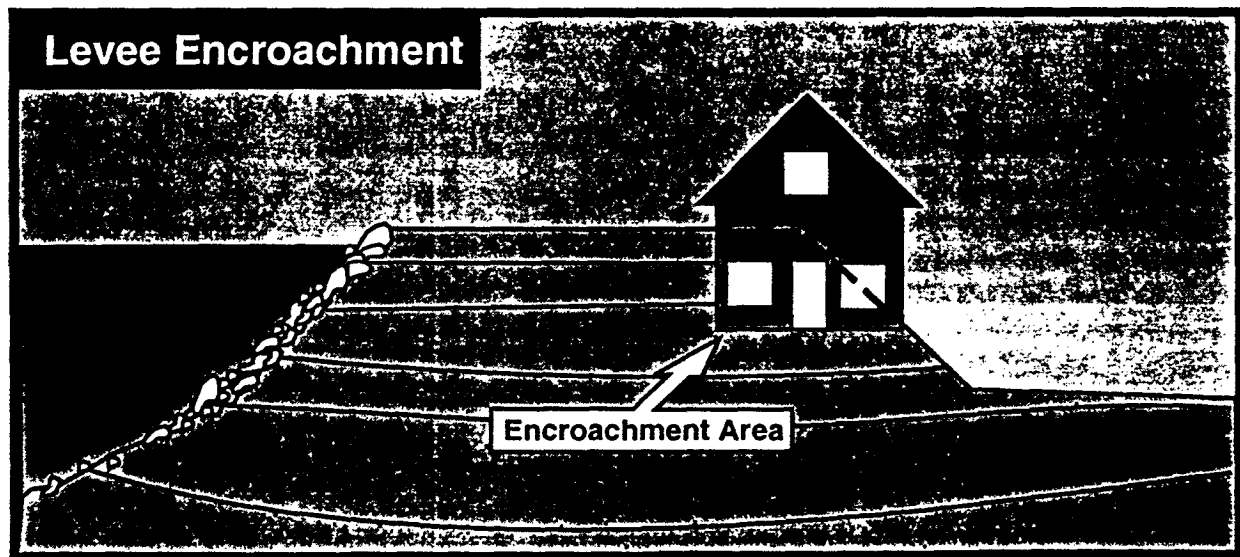


Figure 6: Levee encroachments (from DWR, 1990)

tures (houses, walls, boat docks, etc.) covering the levee slope may hinder inspection of seepage, boils, rodent burrows, sinkholes, sloughs, or cracks.

The problem of encroachments can be seen most clearly on Bethel Island and Hotchkiss Tract, which are the most urbanized areas in the western Delta. Many homes were built on the levee with retaining walls as foundations against the levee slope before the enactment of building setback regulations. Bethel Island Municipal Improvement District adopted an ordinance in June 1989 which established setback regulations. Efforts to identify all the encroachments on these two islands have been completed. Encroachment control plans are currently under development.

### Erosion

Levee waterside slopes are subject to varying erosional effects from channel flows, tidal action, wind-generated waves, and boat wakes. The accelerated growth in recreational use in recent years by pleasure boaters, anglers, and water skiers has intensified this erosion.

The USGS found that about 20 percent of the annual energy dissipated against the levees could be attributed to boat-generated waves in a typical narrow channel subject to both winter flood flows and heavy boat traffic. In a channel relatively unaffected by winter flood flows, energy dissipation from boat-generated waves ranges from about 45 to 80 percent of the total, depending upon wind movement and other factors.

Erosion is often reduced by placing rock revetment (riprap) or a berm on the waterside levee slope. By absorbing the energy of wind-generated waves and boat wakes, berms and revetments provide a barrier that dissipates the water-borne energy. Many levees were originally constructed so as to provide a berm. In most cases, however, these buffers between the main channels and the levees were themselves unprotected from erosive forces and therefore have been lost. Consequently revetment is the primary source of erosion protection used today.

Vegetation is desirable in controlling ero-

sion. However, the continual wave action at normal water levels frequently undercuts vegetation at the waterline, and progressive caving erodes the levee slope. In some places, dense stands of vegetation obstruct the view of levee inspectors and make it difficult or impossible to detect problem areas. In addition, high winds can topple large trees on the levee, exposing the levee to increased erosion and leaving large gaps in the levee.

### Deformation

Levee foundations consisting of soft organic soils and peats are analogous to toothpaste; as the pressure on the tube increases, the toothpaste squeezes out. Similarly, when fill is placed over the soft foundation soils, the soil deforms and bulges, migrating to the path of least resistance. As these softer blocks of peat squeeze out, cracks, fractures, or sinkholes can develop which encourage seepage and may lead to piping. To prevent the deformations from leading to a levee failure, large berms placed at the landside toe have been effective in controlling deformation, thus effectively "capping" the soft peat.

Levee work performed on Twitchell and Sherman islands involved significant berm placement to control deformation and improve stability. These recent experiences clearly demonstrate the value of understanding deformation and how it can be controlled by thorough engineering design and construction.

### Seepage

The constant elevation difference between the higher channel water surface and the lower ground surface of many Delta islands causes a continual seepage of water through and beneath the levees from the channels to the interior of the islands. Seepage tends to increase with time as land subsidence lowers the island ground surface. This seepage can result in levee instability, loss of agricultural production, and higher power costs for drainage pumps.

Levee instability can result from saturation and from removal of levee material by water seeping through the levee. In some instances, saturated soils extend 1,000 feet into the islands.

Visible flows occur in some places at the levee toe and in the toe drain ditches.

### **Sinkholes**

Sinkholes are depressions in the landside of the levee that are typically wet or filled with water. These holes can range in depth from a few inches to many feet and are between 2 and 10 feet in diameter. Instances of the spontaneous development of sinkholes on levee back slopes are periodically reported on the deep peat islands. They are very disturbing, since they connote the existence of a void system and transport mechanism within the levee which can undermine levee integrity, giving no warning until surface collapse occurs. Further, the uncertainty regarding the process of sinkhole formation makes predicting sinkholes difficult.

An investigation was conducted on Sherman Island in 1991 to assess the causes of sinkholes. The study did not answer all questions regarding sinkholes and the results may not be applicable to other sinkhole situations. Nevertheless it did provide major insight into the sinkhole phenomenon at that particular location, and it provided useful background knowledge for assessing other sinkhole occurrences.

Potentially key characteristics identified at the Sherman Island sinkhole locations were:

- The presence of fissures in the peat below the levee fill.
- The existence of a relatively free flow of water through the levee from the river and into the sinkhole.
- The non-cohesive, easily erodible/transportable nature of the sandy levee fill.

The presence of fissures beneath the sinkholes is the most fundamental piece of new data. It means that a sinkhole can form by a relatively simple process of downward migration of material into and along the fissure. The fact that the levee is formed of easily eroded material is a further aid to sinkhole formation.

Corrective measures at Sherman Island to mend the sinkholes involved trying to fill the fissures by grouting, surface filling and compaction, and adding fill to the landside slope of the levee. Sinkholes on Twitchell Island have been successfully controlled by surface filling.

### **Rodent Burrows**

The Delta provides abundant habitat, including marshlands, berms, and levees, for rodents. Properly managed vegetation can reduce rodent problems. Rodent burrows, particularly those of beaver, muskrat, and ground squirrels, can threaten the integrity of a levee. Burrows in levees can weaken the levee section and contribute to levee failure by increasing the potential for piping. Vegetation on levee slopes makes it difficult to detect rodent burrows. In some areas where excessive vegetation occurs (such as dense stands of bamboo or blackberry vines), it is impossible to detect burrows.



# LEVEE DESIGN

Levee design practices can be generally grouped into three periods. The first period is the longest, going from the mid 1800s to some time in the early 1900s when levees were not designed, but simply constructed with respect to water level heights. With the next period, which runs from the 1940s to the 1980s, came the evolution of the standard levee section, which used seepage and stability as levee design criteria, and defined standard levee slopes and widths. The third period began in the early 1980's and extends to the present, where levees are beginning to be designed for site specific conditions using the specialized knowledge and tools of soil mechanics and geotechnical engineering in order to reduce costs.

Levee conditions in the Delta are quite different from those in many other locations, (see Figure 6) where land elevations are above normal water levels. Water forces then act on the levees

only during periods of high water or flooding. In the Delta (see Figure 7), land elevations are generally much lower than normal water levels. Because of this difference, the levees function more as earthen dams which act as continuous water barriers. This difference between many Delta levees and levees in other areas has important implications regarding levee design and reconstruction. For example, most of the Delta levees have to remain fully functional during any improvements or rehabilitation.

## MAIN DESIGN AREAS

Levee failure mechanisms were previously discussed. All of these mechanisms can be placed in five main levee design areas: height, slope and foundation stability, deformation, seepage control, and erosion control.

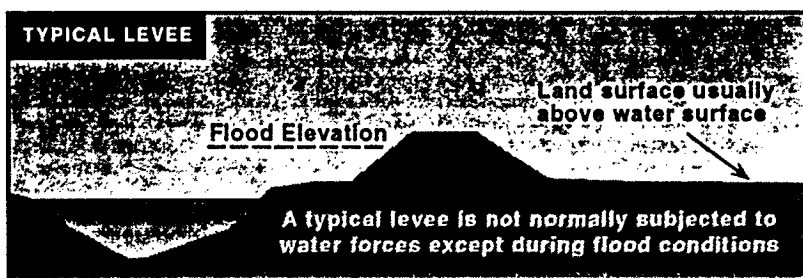


Figure 7: Typical levee

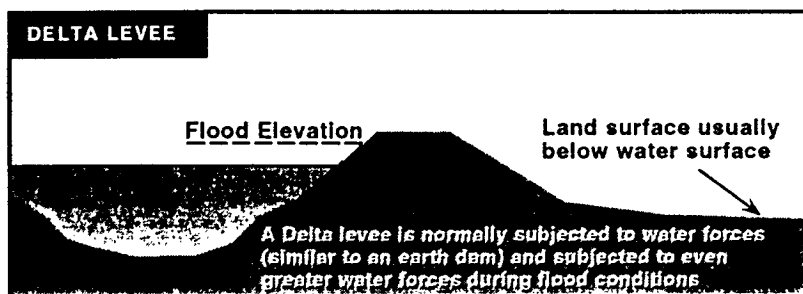


Figure 8: Delta levee

Levee Height - The levee height must be greater than design flood elevations to protect the levee from overtopping and should provide some additional height to increase the margin of safety.

Slope and Foundation Stability - The levee slopes and foundations must be strong enough to prevent gross failure under design flood and seepage conditions. Design alternatives for improving levee stability are flattening the levee slopes and constructing levee toe berms. Flatter slopes improve stability by acting as a counterweight against destabilizing forces and by consolidating and strengthening soft foundation soils.

Seepage Control - Seepage through or beneath levees must be adequately controlled to prevent levee failure by seepage erosion. If seepage gradients and forces are too large, soil can be transported by the seeping water, creating voids in the levee or foundation materials. This process, called "piping", can lead to sudden and catastrophic levee or foundation failure.

Deformation - Movements, displacements, and settlements during the levee service life must be within a tolerable range. Many Delta levees experience relatively large deformations because of the widespread soft peat and clay foundation conditions.

The deformation of levees founded on soft soils can be controlled by constructing the levee improvements in stages. This provides time for the foundation soils to adjust to the new levels of stress with corresponding increases in strength. The reason that construction in stages controls deformations is that soft peats and clays usually display their lowest strengths immediately after loads are applied; then, with increasing time, the strengths gradually increase.

Erosion Control - Levee slope protection is a key element in rehabilitating and maintaining the integrity of the Delta levees. Potential methods of erosion control include riprap, articulating blocks, grouted rocks, interlocking concrete blocks, vegetation management, geosynthetics, and gabions. These slope protection methods vary widely in character and cost and are discussed in more detail at the end of this section.

## DESIGN PROCEDURES AND METHODS

Available geotechnical design procedures and methods include:

- Field investigation and exploration by borings, cone penetration test soundings, and test pits.
- Laboratory soil testing to determine soil strength, permeability, compressibility, and compaction characteristics.
- Engineering analyses of slope stability, seepage, deformations, and settle-

ment.

- Field instrumentation to measure levee and foundation deformations and piezometric (water) elevations and pressures.

## EVOLVING DESIGN PRACTICE

Levee design practice continues to evolve based on experience accumulated from previous projects and the application of state-of-the-art soil mechanics and geotechnical engineering. A design practice that has worked successfully on several recent levee projects is to:

- Collect, review, and evaluate historical data, information, and aerial photography.
- Conduct geotechnical exploration and laboratory testing.
- Perform engineering analyses and develop feasible design alternatives.
- Consider alternatives which maximize habitat avoidance and perform necessary biological assessment to mitigate unavoidable impacts.
- Select a preferred alternative and do final design of levee improvements.
- Install field instrumentation to monitor levee and foundation behavior during construction.
- Construct levee improvements.
- Monitor and maintain the reconstructed levee.
- Evaluate effectiveness, costs, and results of the design and construction methods.

## RECENT PROJECTS

A similar design practice to that described above was applied to recent projects for Sherman Island, Twitchell Island, and the Thornton levees.

Sherman Island - A section of the Sherman Island levee had experienced extensive cracking. The levee section was improved by constructing an underdrain to collect seepage and by constructing a levee toe berm on the land side.

**Twitchell Island** - A 4-mile section of the Twitchell Island levees was in poor condition and in need of upgrading. A program was designed to include installing a landside underdrain, placing toe berms in stages (see Figure 8), increasing the levee crown width, and flattening the levee backslope. Much of the project has been constructed at a lower cost than had been previously estimated for such an extensive upgrading.

**Thornton Levees** - The Thornton levees had experienced dangerous seepage conditions during previous high water periods. In many sections, the levees are constructed of moderately permeable sands. A design utilizing internal drains (see figure 9) constructed in the levee landside slope was developed to control and collect seepage during high water. The project is scheduled for construction in the near future.

## EROSION CONTROL

The waterside levee slopes are subject to continuing attack by wind, waves, soil move-

ment, and burrowing animals. Slope protection designs attempt to dissipate wave energy without allowing erosion of the slope protection or the soil beneath it.

A number of special problems are involved in providing slope protection for Delta levees:

- Foremost is the fact that many Delta levees constantly have water against them. Therefore they are always under attack and are difficult to maintain.
- Delta levees can provide valuable habitat, recreational opportunities, and aesthetic value.
- Tidal action can cause the water levels in some channels to vary as much as 4 feet daily.
- Existing levee slopes are often steep and irregular, which makes placement of slope protection materials difficult.
- Because many levees are continually settling and require periodic additions of material to maintain freeboard, the slope protection method employed must easily accommodate raising the levee crown.
- Many Delta rivers and sloughs have water velocities strong enough to scour their channels and undermine the levee slope protection.
- Some Delta sloughs and rivers have levees overgrown with trees and other large vegetation. These plants sometimes aid in resisting wave-induced erosion, but they also conceal any weakness and instability that may have developed in a levee. Furthermore, high winds can topple these trees, whose

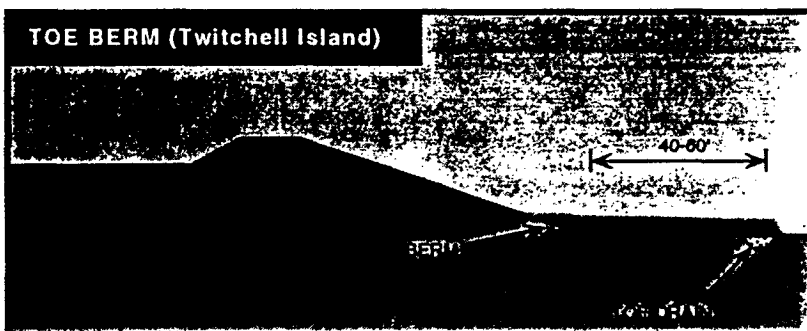


Figure 9: Toe berm and drain for Twitchell Island levee improvement project

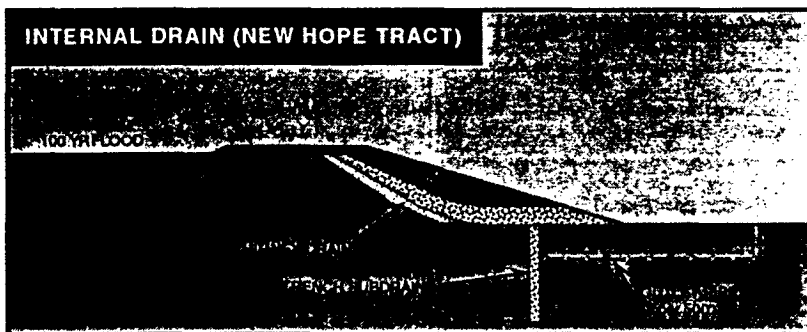


Figure 10: Internal drain design for New Hope levee improvement project

root systems pull away and expose large gaps in the levee.

## **EROSION CONTROL ALTERNATIVES**

Riprap, which is loose, broken rock, has been widely used in the Delta to protect levee slopes from erosion. Quarry rock is the principal type of riprap used, although other materials such as broken concrete has been substituted on occasion. Riprap has been a fairly cost effective means of slope protection. Rock is readily available near the periphery of the Delta and the cost is relatively low. Labor cost in placing the riprap is also relatively low. However, wave action can cause pumping of water through the gaps between rocks and eroding the underlying levee material. The use of a geotextile underneath the riprap layer may greatly improve its long term effectiveness.

Armorflex, a proprietary system, is a type of slope protection in which cellular concrete blocks, either open or closed, are cabled together without fabric encapsulation. The main disadvantage of the Armorflex system is the high labor cost involved in assembling the blocks. Each block must be individually strung onto the cable by hand. The slope on which Armorflex is to be placed must be prepared to a smooth surface, and a geotextile must be placed beneath the blocks. The top of the Armorflex mat must be anchored and the toe of the levee must be protected from scour, either by extending the lengths of Armorflex or placing extra rock.

Vegetation on levee slopes is important for environmental and aesthetic reasons. Vegetation also helps protect levees from erosion caused by precipitation and wavewash. The roots of plants help to hold the soil in place, and the leaves and stems help dissipate wave energy. Vegetation alone, however, has not proven to be an effective slope protection in many reaches in

the Delta. Because vegetation does not usually extend below the mean water level, the levees are exposed to wave energy during low tides. In places of average to steep slopes, large waves commonly erode the soil and dislodge vegetation. Further, vegetation shelters burrowing animals and conceals animal dens and tunnels which may have detrimental effects on levee stability.

Controlled or managed vegetation on slopes and waterside berms used in conjunction with riprap or interconnected concrete blocks provides a combination of benefits. Many of the cabled or interlocking systems could be constructed to allow openings for trees or large brush, provided they are not located on steep slopes or near the levee crown. Alternatively, a small waterside berm could be built to support the growth of trees and other vegetation. The slopes above and below the berm could be protected economically and effectively with riprap, leaving the top of the berm to provide the aesthetics and wildlife habitat. A 1992 demonstration project on Staten Island has shown that waterside berms can be quickly and economically constructed and vegetated.

In reality, no single slope protection alternative accomplishes all the aims listed above (see Table 1). Except for riprap and natural vegetation, none of these alternatives has ever been adequately tested in the Delta. Therefore DWR and DFG have implemented levee demonstration projects which maximize fish and wildlife habitat values without using riprap. Alternative demonstration projects were performed in the fall of 1992 using Tri-lock interlocking blocks, Armorflex cabled blocks, and riprap. The results of these projects will help determine the most beneficial alternative. To date, however, nothing has been found to be more cost effective than riprap.

Slope Protection Alternative	System Cost per Sq. Ft. 1,4	Description	Flexibility for Levee Settlement	Ease of Extension in Levee Raising	Relieves Hydrostatic Pressure 5	Deters Burrowing Animals	Possibility of Revegetation	Performance History in the Delta	Ease of Installation	Durability
Riprap	1.75	Broadly graded rocks	Excellent	Excellent	Yes	Fair	Poor	Excellent	Excellent	Excellent
Grouted-rock Soil-cement		Cemented masses or layers	Poor	Poor	No	Excellent	Poor	Unknown	Poor	Excellent
Articulating Block	5.25-5.75	Nylon fabric connecting & forming concrete blocks	Fair	Poor	Yes	Fair	Poor	Unknown	Fair	Good
Armorflex 3	5.00-5.50	Preformed concrete blocks joined by cables	Excellent	Fair	Yes	Fair	Good	Unknown	Good	Excellent
Tri-Lock, Armorloc 3, & Monoslab	5.00, 4.25-4.50, 4.00	Interlocking preformed concrete blocks	Good	Poor	Yes	Fair	Good	Unknown	Fair	Excellent
Vegetation (Co-Composting) 2	1.50	Plants growing on slope	Excellent	Excellent	Yes	None	Excellent	Poor	Excellent	Poor
Geosynthetic	0.30	Porous synthetic covering	Excellent	Excellent	Yes	Fair	Good	Poor	Fair	Poor
Reno Matress	2.25-3.00	Rectangular wire	Fair	Fair	Yes	Fair	Poor	Unknown	Good	Excellent

- 1 Cost of material and installation only. Cost of slop preparation will vary with slope protection method and condition of slope.
- 2 Co-composting may be used to help establish vegetation on the slopes. However, the existing and surrounding peat soil is as good a growth medium.
- 3 Requires geosynthetic or graded filter beneath rocks.
- 4 Cost may vary with quantity. Area to be covered for pricing ranged from 50 feet x 20 feet to 5 miles x 20 feet
- 5 Slope protection must be permeable enough to allow water collected behind the protection to equalize with the water in the channel.

Table 1: Slope protection alternatives (From DWR, Feb 1990)



# LEVEE MATERIAL

On the basis of typical levee sections, the Corps determined that about 55 million cubic yards of material would be required for construction to rehabilitate substandard Delta levees. It was also determined that because of a general scarcity of soils suitable for levee construction within the Delta, a significant portion of the construction material would have to be imported at a higher cost.

An economical, easily accessible nearby source of fill material for Delta levees is sediment deposited in adjoining Delta waterways and ship channels. These adjoining channels have historically been the source of most of the Delta levee material. However, removing material near the waterside toe of levees causes stability and seepage concerns. Borrowing channel material is also becoming more difficult due to Endangered Species Act restrictions. Dredging of the Sacramento and San Joaquin River ship channels should continue to provide significant quantities of sandy material, and through increased coordination of dredging and levee repairs, this material could become an even more valuable resource.

Land acquired for the purpose of creating wildlife habitat typically requires moving large amounts of earth to create the desired habitat conditions. Material excavated from these areas can be an economical source of levee fill material. For example, habitat plans under development for 500 acres of DWR land in the north Delta may provide several hundred thousand cubic yards of material to rehabilitate New Hope Tract levees.

Another source of levee material is the natural sand deposits that exist on some islands. Recent levee improvement projects on Webb, Holland, and Bouldin Islands effectively utilized sand mounds on the islands as economical sources of fill. Roughly 2 million cubic yards was placed at an average cost of \$5.00/cy whereas on

Twitchell Island, 500,000 cy's was imported at costs exceeding \$10/cy.

## **LONG-TERM MANAGEMENT STRATEGY**

A program for use of materials dredged from ship channels and harbors for levee rehabilitation could greatly reduce these costs. The Long-Term Management Strategy (LTMS) is a multi-participant program established and run by the U. S. Environmental Protection Agency, the Corps, the San Francisco Regional Water Quality Control Board, and the San Francisco Bay Conservation and Development Commission to provide information and prepare plans to designate and manage dredging and disposal from the San Francisco Bay over the next 50 years. Potential disposal options to meet the region's dredging requirements include ocean site(s), in-Bay sites, and reuse/nonaquatic alternatives, including marshland creation projects. Dredging in the San Francisco Bay area creates an annual disposal requirement of approximately 8 million cubic yards (mcy) of dredged material. Moreover, there are proposals to deepen existing projects that total approximately 19 mcy.

Given the continuing need for levee fill material due to the depletion of local borrow sources, sediment dredged from Bay channels is a potentially valuable resource for levee repair. A potential barrier to utilization is the impact on water quality since the dredged sediment originates from a saline environment. Therefore, future reuse plans must recognize that imported fill material must be carefully managed to prevent degradation of Delta water quality.

The Department, in coordination with the Corps and the Regional Water Quality Control Board, has been conducting demonstration projects to determine the viability of relocating Bay material to the Delta. In 1990, a demonstra-

tion project on Sherman Island utilized 1,600 cy of dredge sediments from Suisun Slough to construct a landside berm. An extensive monitoring program over a 2-year period showed no soil contamination or any adverse impact on water quality resulting from the placement of these marine sediments. Following the successful Sherman Island Project, 50,000 cy of sandy material dredged from Suisun Bay Channel and stored on Simmons Island was transported to Twitchell Island and incorporated into the levee

on Twitchell Island. Water quality monitoring to date has not identified any significant impacts due to increased salinity.

These projects have demonstrated an environmentally sound solution for dredge disposal as well as for levee maintenance and improvement. Building on the success of these reuse projects, future plans include another beneficial reuse project for levee improvements on Jersey Island.

# LEVEE FUNDING

Besides the local land owners, Federal Disaster Relief Funds, administered by the Federal Emergency Management Agency, have historically been a significant source of revenue to repair the levees. Severe flooding, causing an estimated \$100 million in damage, occurred in the Sacramento-San Joaquin Delta between 1980 and 1986. Eighteen islands were inundated during this period, prompting five Presidential disaster declarations and one State emergency declaration. During this period, FEMA authorized reimbursement of approximately \$65 million for emergency repair work.

As an alternate means to assist the local agencies, Senate Bill 541 (Way), was enacted in 1973. This bill provided State reimbursement of a portion of the maintenance costs for nonproject levees. Today, nonproject levees are funded through the Delta Flood Protection Act of 1988 (Senate Bill 34). The bill created the Delta Flood Protection Fund and declared legislative intent to appropriate \$12,000,000 each year to the fund through fiscal year 1998-99. This appropriation is divided as follows: \$6,000,000 for the Delta Levee Subventions Program, which provides local assistance to agencies in the Delta for the maintenance and improvement of Delta levees, and \$6,000,000 for Special Projects, which implements levee improvement measures on the eight western Delta islands and the communities of Walnut Grove and Thornton. Due to State funding priorities, appropriations made to the Delta Flood Protection Fund in the past 2 years have been substantially less than anticipated. Funding this fiscal year has been restored to the intended

appropriation of the Act.

On August 19, 1991, the Corps, DWR and The Reclamation Board signed an agreement to begin a special study on 57 islands in the Delta, which are protected by non-project levees. Potentially, this six year study could lead to federal involvement in projects that will improve flood protection, environmental restoration, and correct navigation related problems in the Delta.

With regard to future costs, the Corps in 1982 estimated that almost \$1 billion would be needed to rehabilitate levees on 53 Delta islands. Costs for some of the worst levees in the western Delta ranged from \$2-4 million/mile. However, improvements made in 1992 and 1993 on extremely fragile levees in the western Delta have been completed using an innovative design for less than \$1.5 million per mile. Even after accounting for recreation and maintenance, these costs are less than the estimates made over 10 years ago to repair the same levees. Use of new designs, extensive monitoring, and economical borrow sources are all factors which need to be considered in developing realistic future costs.

Clearly, however, rehabilitation costs exceed the ability of most Delta landowners to rehabilitate their levees. Funding through SB 34 has provided for significant levee improvements, but is insufficient to properly rehabilitate all Delta levees. Therefore, a comprehensive cost sharing arrangement needs to be established which will address all the beneficiaries. Cost sharing arrangements similar to those being forged with the LTMS program will help to meet this objective.



# BIBLIOGRAPHY

1. California Department of Water Resources, *Delta Levees Investigation, Bulletin 192-82*, December 1982.
2. Stuart A. Rojstaczer, *Evaluation of Selected Data to Assess the Causes of Subsidence in the Sacramento-San Joaquin Delta, California*, Sacramento, California, 1991.
3. California Department of Water Resources, *Delta Atlas*, 1993.
4. California Department of Water Resources, *Preliminary Evaluation of Measures for Protecting Beneficial Uses of Waters of the Sacramento-San Joaquin Delta*, December 1986.
5. U. S. Army Corps of Engineers, Sacramento District, *Sacramento-San Joaquin Delta Investigation*, July 1979.
6. California Department of Water Resources, *Actions and Priorities*, March 1990.
7. U. S. Geological Survey, *Water Fact Sheet*, 1991.
8. California Department of Water Resources, *Delta Subsidence*.
9. Roger Foott Associates, Inc., *Threatened Levees on Sherman Island*, Berkeley, California, 1992.
10. *Delta Flood Protection Act of 1988: Senate Bill No. 34*
11. California Department of Water Resources, *Delta Levee Slope Protection Alternatives*, February 1990.
12. John Thompson, *Discovering and Rediscovering the Fragility of Levees and Land in the Sacramento-San Joaquin Delta, 1870-1879 and Today*, March 1982.
13. Stuart A. Rojstaczer and Steven J. Deverel, *Time Dependence in Atmospheric Carbon Inputs From Drainage of Organic Soils*, American Geophysical Union, Geophysical Research Letters, Volume 20, Number 13, July 9, 1993

# **DELTA LEVEE AND CHANNEL MANAGEMENT ISSUES**

## **REVIEW OF SEISMIC STABILITY ISSUES**

**Prepared by:      Les Harder, Chief, Dam Projects Branch,  
                         Division of Design and Construction  
                         Department of Water Resources**

State of California  
The Resources Agency  
Department of Water Resources  
DIVISION OF DESIGN AND CONSTRUCTION

**REVIEW OF SEISMIC STABILITY ISSUES  
FOR SACRAMENTO-SAN JOAQUIN DELTA LEVEES**

Briefing Paper Prepared for the  
California Bay-Delta Oversight Council



Memorandum Report

October 1993

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REVIEW OF SEISMIC STABILITY ISSUES  
FOR SACRAMENTO-SAN JOAQUIN DELTA LEVEES

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for

The California Bay-Delta Oversight Council

## **FOREWORD**

This memorandum report is intended as a briefing paper for the Bay-Delta Oversight Council on seismic stability issues associated with levees in the Sacramento-San Joaquin Delta. Most of the information in this report has been obtained from the Department's 1992 Phase I report entitled "SEISMIC STABILITY EVALUATION of the SACRAMENTO-SAN JOAQUIN DELTA LEVEES - Preliminary Evaluations and Review of Previous Studies." Further details and references can be obtained in the 1992 report.

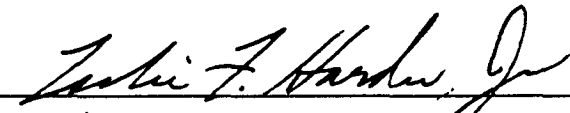
The studies were performed with guidance from a Board of Consultants established by the Department. This board consists of three experts in the fields of seismology, earthquake engineering, and geotechnical engineering.

The evaluations were performed to provide information as to the susceptibility for Delta levees to sustain damage during earthquakes. With this information, the degree of risk can be estimated in a general way and a rational approach can be pursued in the management of existing and future Delta facilities and resources.

State of California  
The Resources Agency  
Department of Water Resources  
DIVISION OF DESIGN AND CONSTRUCTION

ENGINEERING CERTIFICATION

This report has been prepared under my direction as the professional engineer in direct responsible charge of the work, in accordance with the provisions of the Professional Engineers' Act of the State of California.

  
\_\_\_\_\_  
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Date: October 8, 1993



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## 1. EXECUTIVE SUMMARY

The islands in the Sacramento-San Joaquin Delta lie commonly 10 to 15 feet below sea level and are protected by levees against inundation from the adjoining rivers and sloughs. The original levees were constructed in the late 1800s to have heights of about five feet and were generally founded on soft, organic soils common in the Delta. Due to continued settlement of the levees and subsidence of the island interiors, it was necessary to continually add material to the levees in order to maintain freeboard and structural stability. Over the last century, the levees have significantly increased in size and now are commonly between 15 and 25 feet in height.

Most of the levees were built of non-select, uncompacted materials which were added piecemeal in lifts and/or berms. The sidedraft-clamshell dredge was commonly used to build the levees and is still used today to maintain them. The resulting structures are embankments composed of mixtures of uncompacted sands, silts, clays, and organic soils. There has often been a concern for the performance of these levees during earthquakes, as similar structures commonly experience liquefaction and damage during moderate to strong earthquake shaking. Concern has also been raised concerning the liquefaction potential of foundation materials at some islands.

Since reclamation of the Delta began in the late 1800s, bedrock and stiff soil lying beneath the soft organic soils common throughout the Delta have not been subjected to significant earthquake-induced ground motions (accelerations greater than 0.1g). No record of a levee failure, or even significant damage to a levee as a result of earthquake shaking has been found. This indicates that the Delta levee system has never been significantly tested for earthquake shaking. However, there are several active faults located to the west of the Delta which are capable of delivering moderate to large shaking (e.g. Antioch, Greenville, and Coast Range Sierra Nevada Boundary Zone Faults). Such motions could be significantly larger than the relatively small levels of ground motion that the Delta has experienced since the levees were constructed.

Several preliminary studies of the seismic stability of Delta levees have been completed in recent years. Such studies are preliminary in nature because of the long lengths of levees involved (over 1,100 miles), the lack of information

concerning the levees and their foundations, and the great unknowns related to the capabilities of the organic soils beneath the levees to either amplify or attenuate ground motions. Nevertheless, most of the studies seem to conclude that levee failure would result if surface motions exceeded some critical acceleration, generally reported to be between 0.1g and 0.2g.

The amount of levee damage and/or failure which would be predicted involves several factors. Two of the principal factors involve the period of exposure and the amount of ground motion amplification which could be experienced in the foundations beneath the levees. Both of these parameters basically involve the level of shaking which the levee would experience. For longer periods of exposure, larger ground motions would be expected to be experienced. This is analogous to recurrence intervals used for storm flood analyses (e.g. 100-year flood). Several seismic studies have used a 30-year exposure period, partly because the United States Geological Service has predicted that a large magnitude ( $M > 7$ ) would have a two-thirds chance of occurring in the San Francisco Bay Area during this period.

The consensus of several studies would seem to suggest that there would probably be levee damage and failure induced in the Delta by earthquake shaking within the next 30 years. Studies by the Department of Water Resources suggest that moderate to moderately high damage and levee failure would be expected during this time period along the western edge of the Delta.

The consequences of levee failure and island inundation depend upon the location of the inundated island and the flow conditions at the time of failure. When a Delta levee fails, water from the adjoining rivers and channels flow toward the island which is flooding. This may lead to reverse flows in some channels and draw salt water deeper into the Delta. During typical winter flood flows there is generally so much flow moving towards the San Francisco Bay that salt water is generally not pulled into the Delta. However, during low flow conditions, salt water intrusion is quite possible. The result could be so much salt water intrusion that water export might have to be halted and increased upstream reservoir releases might be necessary to dilute and flush out the intruded saline water. Unlike many levee failures during winter floods, an earthquake-induced levee failure during low flow conditions (e.g. drought or summer months) could seriously disrupt water deliveries.

Further investigations involving field and laboratory testing are needed to reduce the uncertainties and better define the expected performance of the levees during future earthquakes. In particular, the ability of the soft organic soils beneath the levees to either amplify or dampen motions needs to be determined. This material property significantly affects the predicted performance of the levees and our understanding of this property is severely limited at this time.

## 2. LEVEE HISTORY AND PERFORMANCE OF LEVEES DURING EARTHQUAKES

### 2.1 REGIONAL GEOLOGY

The Sacramento-San Joaquin Delta, located at the confluence of the Sacramento and San Joaquin Rivers, is part of a large basin commonly known as the Central Valley of California. In recent geologic time, this area has undergone several cycles of deposition and erosion, resulting in the accumulation of a few hundred feet of poorly consolidated to unconsolidated sediments.

Delta peats and organic soils began to form about 11,000 years ago during one of the rises in sea level. This rise in sea level created tule marshes that covered most of the Delta. Peat formed from repeated burial of the tules and other vegetation growing in the marshes. Presented in Figure 1 is an organic isopach map of the Delta showing the different thicknesses of organic soils throughout the Delta. In general, the thicknesses of these soft soils range between 0 and 50 feet, but are commonly about 10 to 30 feet throughout most of the Delta.

During the cycles of erosion and deposition, streams were entering from the north, northeast, and southeast. These included the Sacramento, Mokelumne, and San Joaquin Rivers. As the rivers merged, they formed a complex pattern of islands and interconnecting sloughs. River and slough channels were repeatedly incised and backfilled with sediments with each major fluctuation. Along many of these channels, sediment deposited during overbank flows formed small, natural levees composed of intermixed mineral and organic soils.

### 2.2 LEVEE CONSTRUCTION AND ISLAND RECLAMATION

During the late 1800s, Delta inhabitants began fortifying existing natural levees and draining inundated islands in the Delta for agricultural use. Most of the early levees in the Delta were constructed by Chinese laborers using hand shovels and wheelbarrows, and some were built using scrapers pulled by horses. Later, the sidedraft-clamshell dredge was used. The levees were generally built of non-select uncompacted materials without engineering design and without good construction methods. The original levees were usually less than five feet high, but settlement of the levees and subsidence of the interior island soils have required the

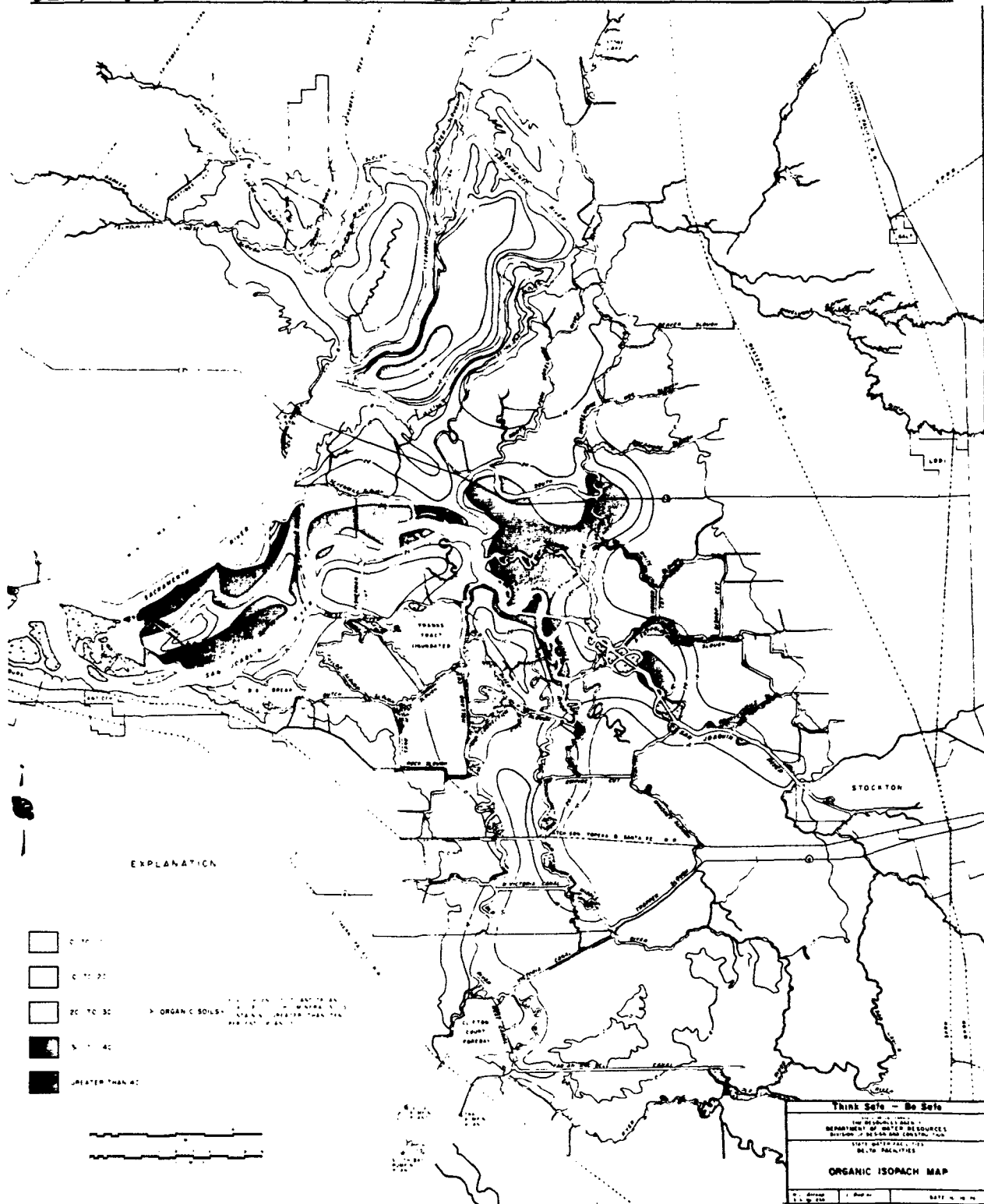


FIGURE 1: ORGANIC ISOPACH MAP OF THE DELTA (from DWR, 1976)

continued addition of fill on the levees to maintain protection against overtopping by waters of the Delta.

The interiors of many islands are now commonly 10 to 15 feet below sea level. Presently, some levee crowns are 20 to 25 feet higher than the interior of their respective islands. In order to maintain stability of the high embankments over the relatively soft soils in the Delta, large berms or buttresses have had to be added to the levee sections. This process has resulted in the original 5-foot-high levees growing into relatively large embankments. Figure 2 illustrates the development process that many typical Delta levees have experienced.

### 2.3 POTENTIAL MODES OF EARTHQUAKE-INDUCED LEVEE FAILURE

Levee failure is defined as sufficient levee distress as to result in inundation of the protected area, in this case a Delta island or tract. For earthquake shaking to induce a levee failure, one of the two general failure modes must occur:

- o Earthquake shaking produces sufficient deformation or settlement in a levee and/or its foundation to result in its being overtopped and washed away by the waters it is retaining.
- o Earthquake shaking produces sufficient deformation or settlement in a levee and/or its foundation to result in severe cracking of the levee. Such cracking then allows water to seep through the levee along preferred paths and gradients that result in internal erosion and the piping away of the embankment.

### 2.4 LIQUEFACTION AND STRENGTH LOSS

Many types of soils that are dry or dense exhibit no strength loss during the cyclic loadings common to earthquakes, and structures composed of or founded on such soils behave well. However, soils which are soft and/or loose and saturated often lose considerable strength during cyclic loadings. The ultimate strength loss is known as **LIQUEFACTION** and is a state in which the soil loses most of its original strength and behaves essentially as a viscous liquid. Loose, cohesionless soils such as sands and silts below the ground water level commonly liquefy during earthquakes. There have been several instances where structures or embankments built

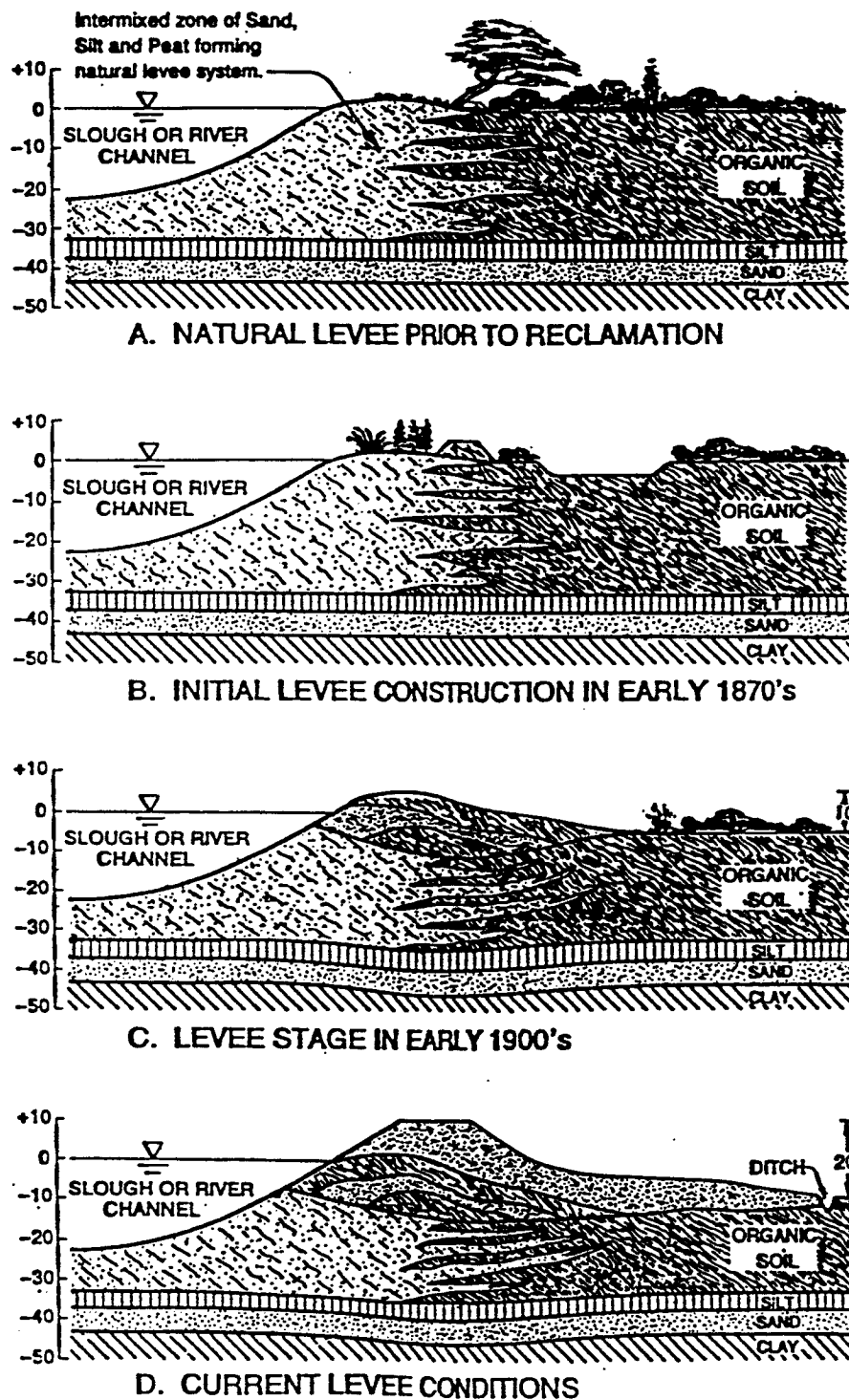


FIGURE 2: DEVELOPMENT OF DELTA LEVEES (from DWR, 1992)

on such soils have experienced dramatic failures due to soil liquefaction.

Liquefiable soils are generally found in recent deposits along rivers and estuaries, and in man-made deposits such as hydraulic fills. It appears generally well-established that at least some of the levees in the Delta contain liquefiable soils and that there are also locations where river sediments which form the foundations of levees are also susceptible to liquefaction.

There is very little available information, however, to help determine if the organic soils comprising some of the levees and their foundations are susceptible to significant strength losses.

## 2.5 PROMINENT EXAMPLES OF EARTHQUAKE-INDUCED LEVEE FAILURES

In many areas of the world, levees which sustain medium to strong earthquake shaking commonly experience significant damage. This is because levees are often built of loose materials, are saturated because they retain water, and liquefy whenever earthquake shaking is high enough. Listed below are two prominent examples of levee failures which occurred when earthquake shaking induced liquefaction within either the levee fill or its foundation:

### Solfatara Canal Levee

The Solfatara Canal is located in Mexico south of the California border near Mexicali. On May 18, 1940, a Magnitude 7.1 earthquake occurred along the Imperial Fault running from California south through Mexico. Approximately 12 miles of this canal levee were essentially destroyed by very strong earthquake shaking. Levee embankments settled as much as seven feet into their foundations, leaving very little residual fill to retain canal water (see Figure 3). There was also extensive damage to the levees of the All-American, Alamo, and Cerro Prieto Canals in this area following the earthquake.

### Moss Landing Tide Gate Embankment

The Moss Landing Tide Gate Embankment is an embankment constructed across an estuary near Moss Landing, California. The purpose of the embankment is to provide vehicle access to the Moss Landing State Beach. A culvert pipe had been placed within the embankment to

allow estuarial tidal flows to pass through the embankment. During the 1989 Loma Prieta Earthquake, the site experienced moderate earthquake shaking with peak accelerations estimated to be about 0.25g. This triggered a liquefaction flow failure of the embankment, resulting in approximately 4 feet of settlement (see Figure 4). As the embankment was only about 6 feet high, most of the entire height of this levee-like embankment was lost as a result of the earthquake.

The above examples of embankment behavior are cited because of similarities between the embankments and many levees which exist in the Delta. Both embankments retain channel or estuarial water and have saturated lower embankments and foundations as do Delta levees. Because there are over 1,100 miles of levees in the Delta, there is no one typical cross section of geometries and materials that is representative of all of the Delta levees. However, many levee reaches in the Delta are constructed of and/or are founded on saturated, sandy soils similar to those which liquefied at Solfatara and Moss Landing. While the heights of the Solfatara and Moss Landing embankments are generally about half the heights of typical Delta levees, general orders of magnitude for deformations would be expected to be similar for similar levels of earthquake shaking.

## 2.6 HISTORICAL SEISMICITY IN THE SACRAMENTO-SAN JOAQUIN DELTA

A review of available information indicates that between 1855 and 1989, approximately 55 earthquakes with magnitudes above 4.5 occurred close enough to the Delta to induce noticeable effects. However, none of these events are believed to have induced even moderate levels of shaking. The information indicates that the bedrock and stiff soil sites located at the periphery of the Delta have experienced peak accelerations no higher than about 0.1g to 0.15g. Within the central portions of the Delta, base motions would be expected to have been less than 0.1g. Even the 1906 San Francisco Earthquake is estimated to have generated peak accelerations of 0.08g or less within most of the Delta region.

## 2.7 PERFORMANCE OF DELTA LEVEES DURING PREVIOUS EARTHQUAKES

Reviews of newspaper accounts, engineering journals, and eyewitness interviews have shown that there is no evidence that a levee in the Sacramento-San Joaquin Delta has ever failed as a result of earthquake shaking. Moreover, there is no evidence of any Delta levee having experienced significant



FIGURE 3: 1940 FAILURE OF SOLFATARA CANAL LEVEE



FIGURE 4: 1989 FAILURE OF MOSS LANDING TIDE GATE EMBANKMENT

**SEISMIC STABILITY OF DELTA LEVEES**

damage as a result of earthquake shaking. The most serious distress appears to have been the approximate 3 feet of settlement reported for a Santa Fe railroad bridge at the Middle River crossing during the 1906 earthquake. This lack of reported damage is not, however, indicative of a strong levee system. As noted above, the historical seismicity of the Delta is rather low and the level of shaking that has been experienced since island reclamation has been relatively small. Accordingly, the real meaning of the historical record is that the Delta levee system has never been subjected to significant earthquake motion and, in effect, has never really been tested.

It should be pointed out that the strongest earthquake loadings probably occurred during the 1868 Hayward (M=6.8) and 1906 San Francisco (M=8+) earthquakes. During these events, the levee system was not fully developed and the levees were generally less than half of their current height.

It should also be noted that while there is no evidence that any Delta levee has failed due to earthquake shaking, there has been over 140 levee failures and island inundations due to flood flows in the Delta since 1900.

### 3. SEISMIC ENVIRONMENT

#### 3.1 ACTIVE FAULTS

The Sacramento-San Joaquin Delta lies in a seismically active region (see Figure 5). Most of the significant earthquakes which have occurred are associated with fault sources located to the west of the Delta area and are considered part of the San Andreas Fault system (see Figure 6). The San Andreas Fault system refers to the network of faults with predominantly right-lateral strike slip movement that collectively accommodate most of the relative motion between the North American and Pacific plates.

The Delta itself lies astride a physiographic boundary between the Coast Range and the Great Valley. This boundary also appears to represent a tectonic boundary characterized by a zone of thrust faulting, reverse faults, and folding (after Ake, et al., 1991). Many researchers have speculated that this zone may be capable of earthquakes similar to those experienced in Coalinga to the south ( $M=6.7$  in 1983) and in Winters to the north ( $M=6.5$  in 1892). Much uncertainty has surrounded the behavior and location of this potential earthquake source as it has very little surface expression and a very sparse record of seismicity. At least one researcher has indicated that it may be a 15-mile-wide zone of complex faulting running 400 miles along the western edge of the Central Valley. For presentation purposes, its inferred approximate location is shown in Figure 6 as a dotted line with the label of Coast Range Sierra Nevada Boundary Zone.

#### 3.2 PROBABILITY OF FUTURE EARTHQUAKES

One of the ways used to predict future earthquakes is to examine the frequency of historical earthquakes, along with the rate of slip occurring along different faults. The U. S. Geologic Survey has been conducting such studies and one of the facts they have noted is that while the San Francisco Bay Region was very seismically active during the 1800s and early 1900's, there has been a period of relatively low seismic activity in the region since about 1911 (see Figure 7). This period of relative quiet appeared to have ended in 1979. Since 1979, there have been four moderate to large earthquakes in the region. The obvious possibility is that the region is about to enter a cycle of increased seismicity. In fact, as a result of their studies, the U. S. Geologic Survey predicted

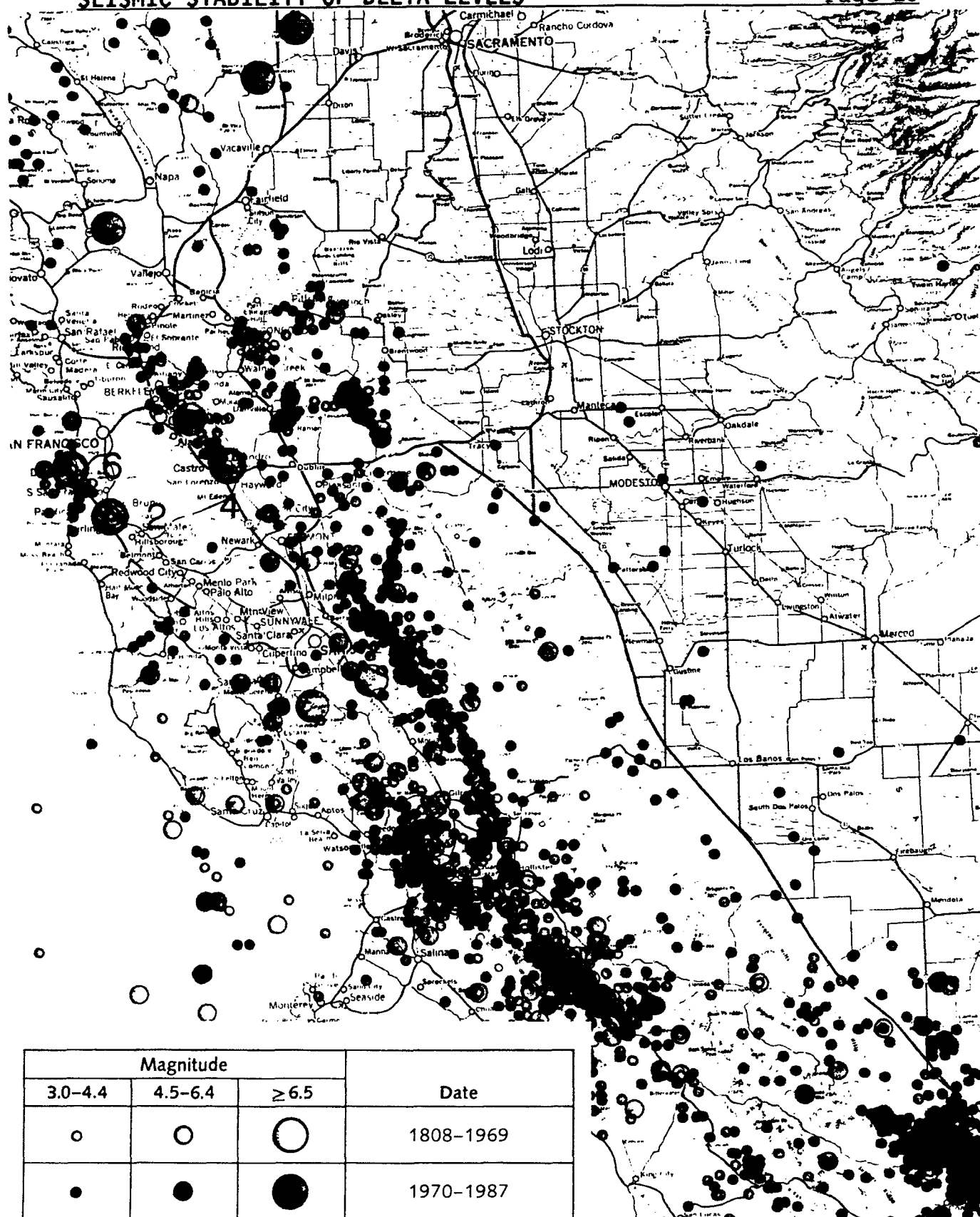


FIGURE 5: REGIONAL SEISMICITY (from USGS, 1987)

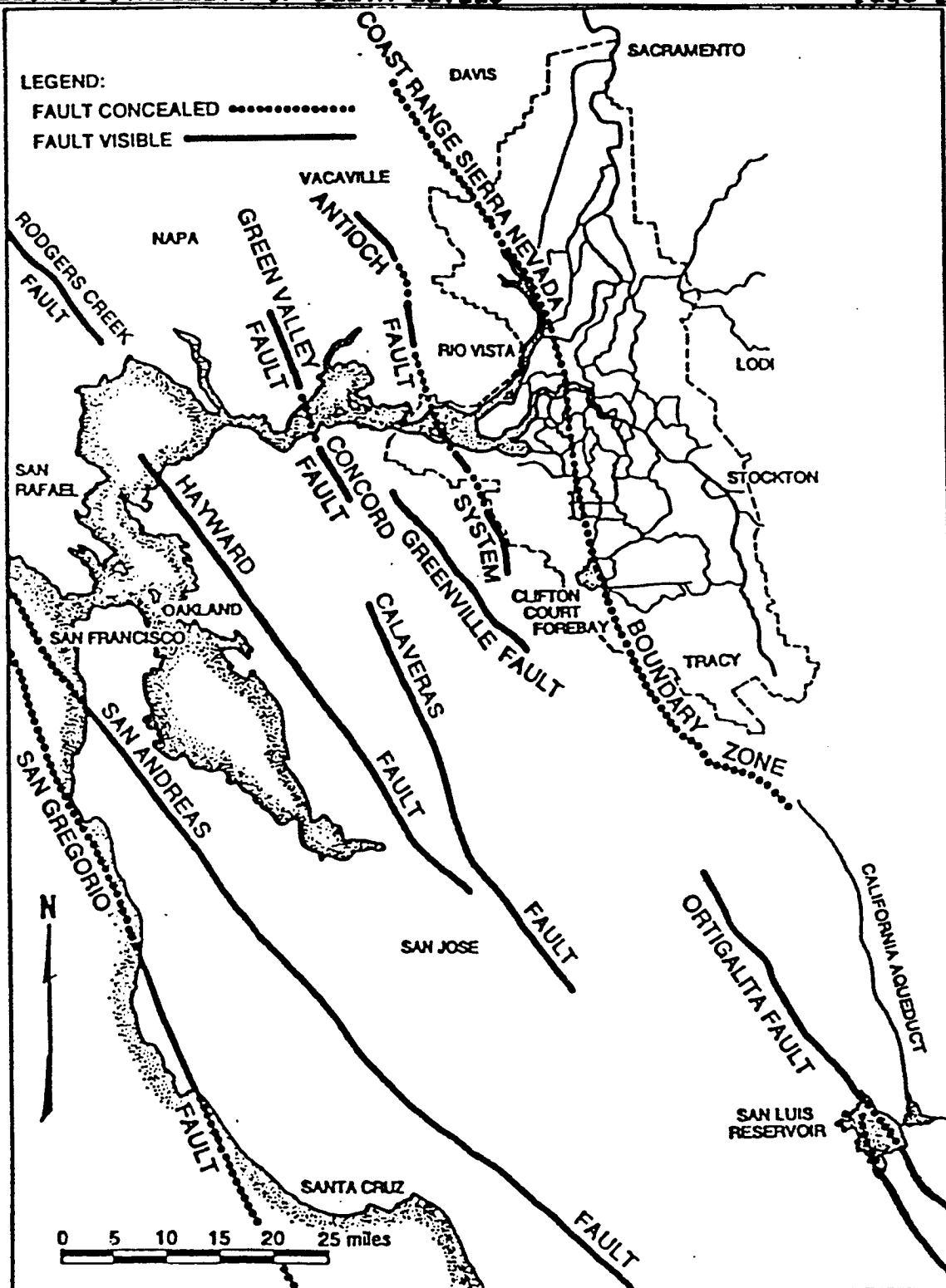


FIGURE 6: REGIONAL FAULT SOURCES (from DWR, 1992)

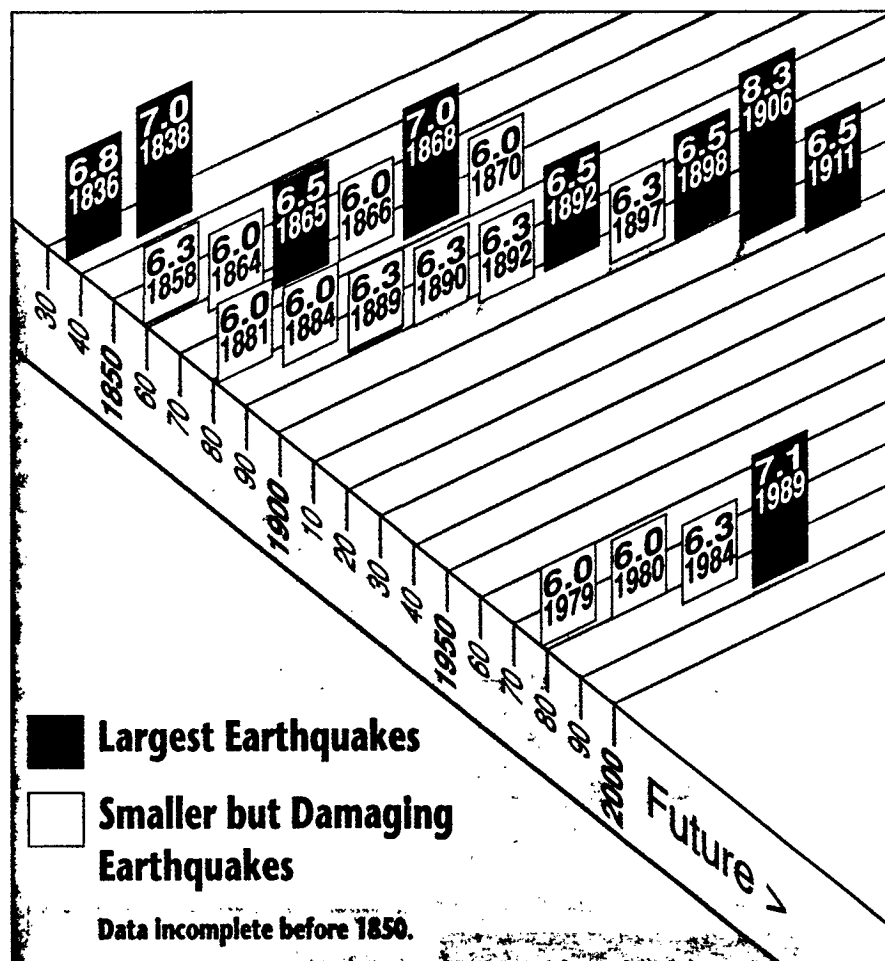


FIGURE 7: HISTORICAL REGIONAL EARTHQUAKES, (from USGS, 1991)

in 1991 that a Loma Prieta-sized earthquake (M~7) has a 67 percent chance of occurring within the next 30 years in the immediate San Francisco-Oakland area on either the San Andreas or Hayward Faults .

### 3.3 PROBABLE BEDROCK MOTIONS BENEATH DELTA WITHIN 30 YEARS

In an effort to estimate probable base motions beneath the Delta within the next 30 years, the Department performed a probabilistic risk analysis. This analysis provided probable peak acceleration levels that would be expected to develop in the bedrock and/or stiff soils lying at depth below the Delta. Several inputs including fault geometry, slip rate, distance from the Delta, maximum earthquake magnitude, and earthquake recurrence intervals were used to develop these estimates.

The results for a 50 percent probability of non-exceedance within an exposure period of 30 years are shown in Figure 8. These results are in the form of contours of peak bedrock acceleration. Predicted base motions range generally between 0.05g and 0.15g for this exposure period. These are relatively small levels of acceleration compared to those which would be predicted in the Bay Area during the same exposure period. As may be observed, the fact that the earthquake sources are generally located to the west of the Delta results in higher accelerations being predicted on the western edge of the Delta than on the eastern side.

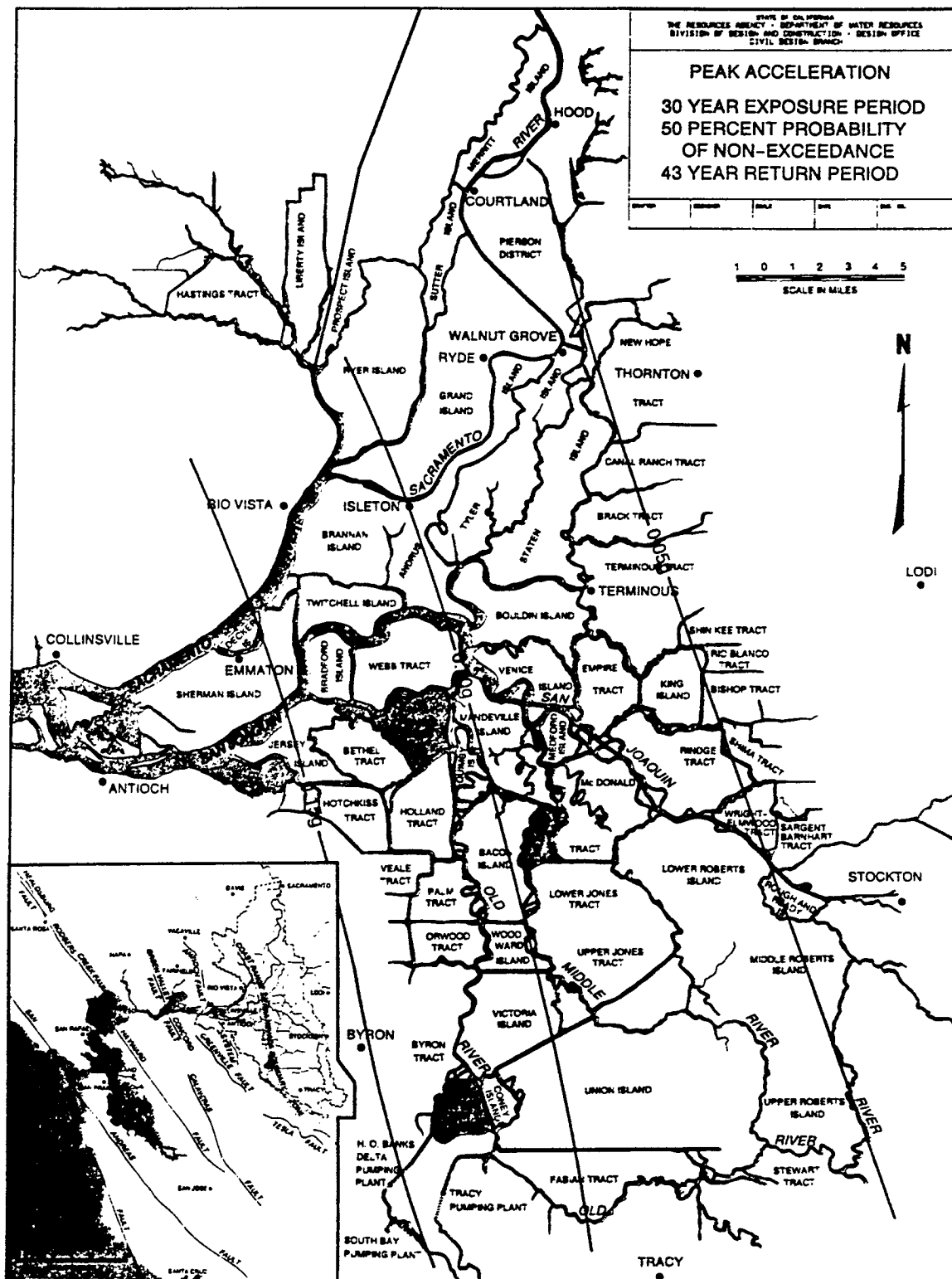


FIGURE 8: PEAK BEDROCK ACCELERATIONS PREDICTED WITHIN  
A 30-YEAR EXPOSURE PERIOD (from DWR, 1992)

#### 4. GROUND MOTION AMPLIFICATION/DAMPING

##### 4.1 AMPLIFICATION THROUGH SOFT CLAYS IN SAN FRANCISCO DURING THE 1989 LOMA PRIETA EARTHQUAKE

One of the most important lessons learned during the 1989 Loma Prieta Earthquake was that soft soils may significantly amplify earthquake motions by factors as high as three to five times the values experienced by more typical deposits. Shown in Figure 9 is the amplification documented at Treasure Island during the Loma Prieta event. The motions recorded on nearby rock (Yerba Buena Island) had peak accelerations of only about 0.07g. The motions recorded on Treasure Island, a hydraulic sandy fill placed over deep deposits of soft clay, had peak values of about 0.16g. This represented an amplification of approximately 2.5.

Similar amplifications were noted at several sites along the margin of the San Francisco Bay and were responsible for much of the prominent damage associated with the earthquake (e.g. Cypress Freeway Collapse). This type of amplification and consequent damage had previously been observed at soft clay sites in Mexico City during the 1985 earthquake. If motions throughout the Bay Area were as low as those recorded at the rock site at Yerba Buena Island, then much of the structural failures and damage would not have occurred. Thus, ground motion amplification through soft soils is an extremely important aspect of seismic loading.

##### 4.2 DAMPING THROUGH SOFT PEATS IN UNION BAY, WA DURING 1969 EARTHQUAKE SEQUENCE

Some investigators have speculated that the soft, peaty soils in the Delta have the same amplification characteristics as do soft clays. As a result, many studies show relatively small bedrock motions being amplified up several times for use in design. However, this may not necessarily be correct if the soft soils in question are fibrous peats. Indeed, the only known earthquake records obtained from a recording site founded on peaty soils indicated severe attenuation or damping rather than amplification. These records were obtained at a site near Union Bay, WA, during a magnitude 4.5 earthquake which occurred about 25 miles away. As shown in Figure 10, downhole seismographs indicated damping factors of as much as 10 (amplification factors as low as 0.1) when ground motions propagated through 58 feet of unconsolidated peat. In effect, the fibrous peat acted as a base isolation system.

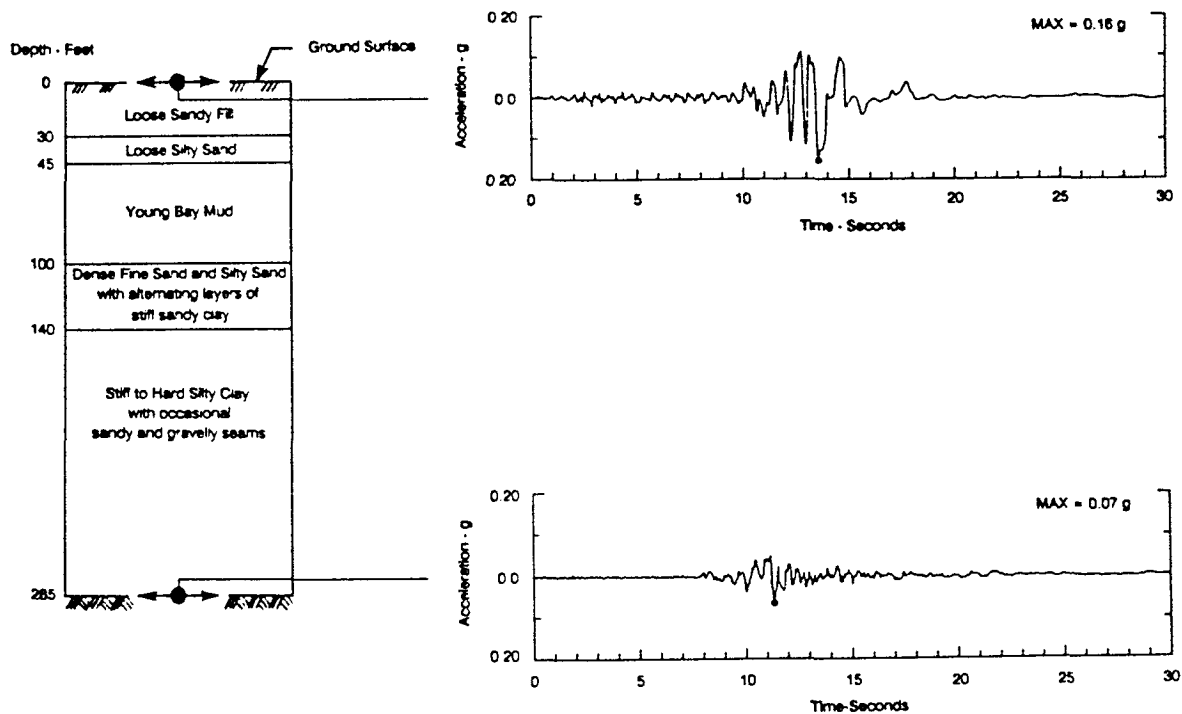
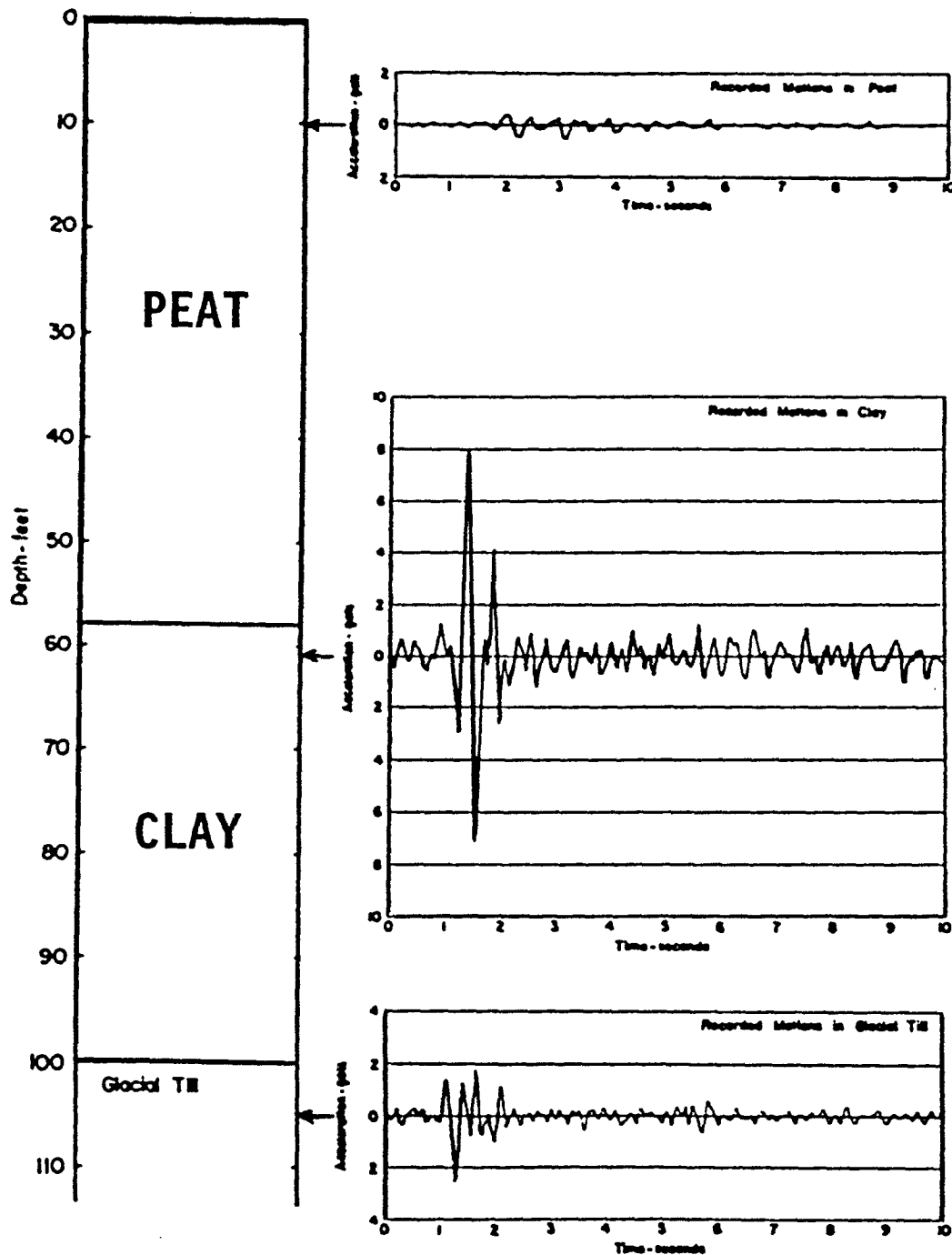


FIGURE 9: SCHEMATIC SOIL PROFILE AND SITE RESPONSE AT THE TREASURE ISLAND STATION (from Seed et al., 1990)



Recorded motions—EW components.

FIGURE 10: 1969 RECORDED MOTIONS FROM UNION BAY, WA  
(from Seed and Idriss, 1970)

#### 4.3 IMPLICATIONS FOR DELTA LEVEES

Many levees in the Delta are founded on soft clayey and peaty soils. The data described in the foregoing sections indicate that such soils can either amplify motions by factors of 3, or dampen motions by factors of 10. With such potentially large values for modifying earthquake motions, the potential for the soft foundations beneath levees to either amplify or damp earthquake motions becomes the dominant element in assessing earthquake stability.

Many foundation deposits in the Delta, however, are somewhat different than sites in either San Francisco Bay or Union Bay. Delta sites may not generally have deep uniform deposits of soft clay, such as in San Francisco Bay. Nor are the peaty soils beneath Delta levees as fibrous or as weak as those in Union Bay. Consequently, the behavior of Delta deposits during earthquake shaking would be expected to be intermediate between the two extremes described above. There would also be expected to be some range in the types of amplification at different locations in the Delta. However, good evidence of their characteristic behavior during earthquake shaking simply does not exist at this time.

## 5. PREVIOUS STUDIES

### 5.1 GENERAL

Several studies and reports concerning seismic hazards and risk analysis have been previously prepared for the Delta region during the last 12 years by government and private concerns. These include the following 12 studies:

Geotechnical Investigation - Earthquake Safety Assessment of the Mokelumne Aqueduct - San Joaquin Delta Crossing (Earth Sciences Associates, 1992).

Preliminary Seismic Risk Analysis, North Delta (U. S. Bureau of Reclamation, 1991).

General Seismic and Geotechnical Risk Assessment, Sacramento-San Joaquin Delta, California (Dames and Moore, 1991).

Seismic Design Criteria, Wilkerson Dam, Bouldin Island, California - DRAFT (Harding Lawson Associates, 1990).

A New View of the Sacramento-San Joaquin Delta (B. J. Miller, 1990).

Preliminary Seismic Risk Analysis, South Delta (U. S. Bureau of Reclamation, 1989).

Estimated Performance of Twitchell Island Levee System (Michael Finch, 1988).

Sacramento-San Joaquin Delta Levee Liquefaction Potential (U. S. Army Corps of Engineers, Sacramento District, 1987).

Seismicity DRAFT (DWR, 1985).

McDonald Island Study, Levee Stability (Dames and Moore, 1985).

Earthquake Damage in the Sacramento-San Joaquin Delta (Michael Finch, 1985).

Mokelumne Aqueduct Security Plan (Converse Ward Davis Dixon, 1981).

All of these previous studies are considered to be preliminary in nature due to the lack of reliable data for the vast Delta levee system. A general consensus among the investigators is noticeable on some of the issues concerning earthquake evaluations of Delta levees:

- o None of the reports could describe with certainty the amplification or attenuation characteristics of the Delta's organic soils. Some did not address this issue at all.
- o Essentially all of the reports state that liquefaction is likely to occur in the foundation soils beneath the organic soil layers. The reports find that, in general, the acceleration values required to trigger liquefaction are between 0.1g and 0.2g.
- o Larger acceleration values are anticipated in the southwestern portion of the Delta than in the northeastern part.
- o None of the studies reported a past levee failure due to earthquake shaking.
- o Most of the investigators recognized a need for additional studies before a more conclusive answer regarding the vulnerability to earthquake shaking could be determined.

Typical types of findings reported in previous studies are illustrated in Figures 11 and 12. Figure 11 shows the results of a liquefaction potential assessment made by the Sacramento District of the U. S. Army Corps of Engineers in 1987. For this assessment, available borehole exploration data was employed to predict the liquefaction potential of the Delta levees and foundations. This plot shows that the central portion of the Delta would be considered to have moderate to high potential for liquefaction. Other portions were considered to have low potential for liquefaction, or insufficient information available for a determination to be made.

Figure 12 presents a summary plot presenting the results from the 1992 Earth Sciences Associates evaluation of liquefaction potential along the Mokelumne Aqueduct. As shown in the figure, there is relatively high potential of liquefaction predicted along the western edge of the Delta within 30 years (about 90 percent probability). This potential generally decreases towards the eastern edge of the Delta.

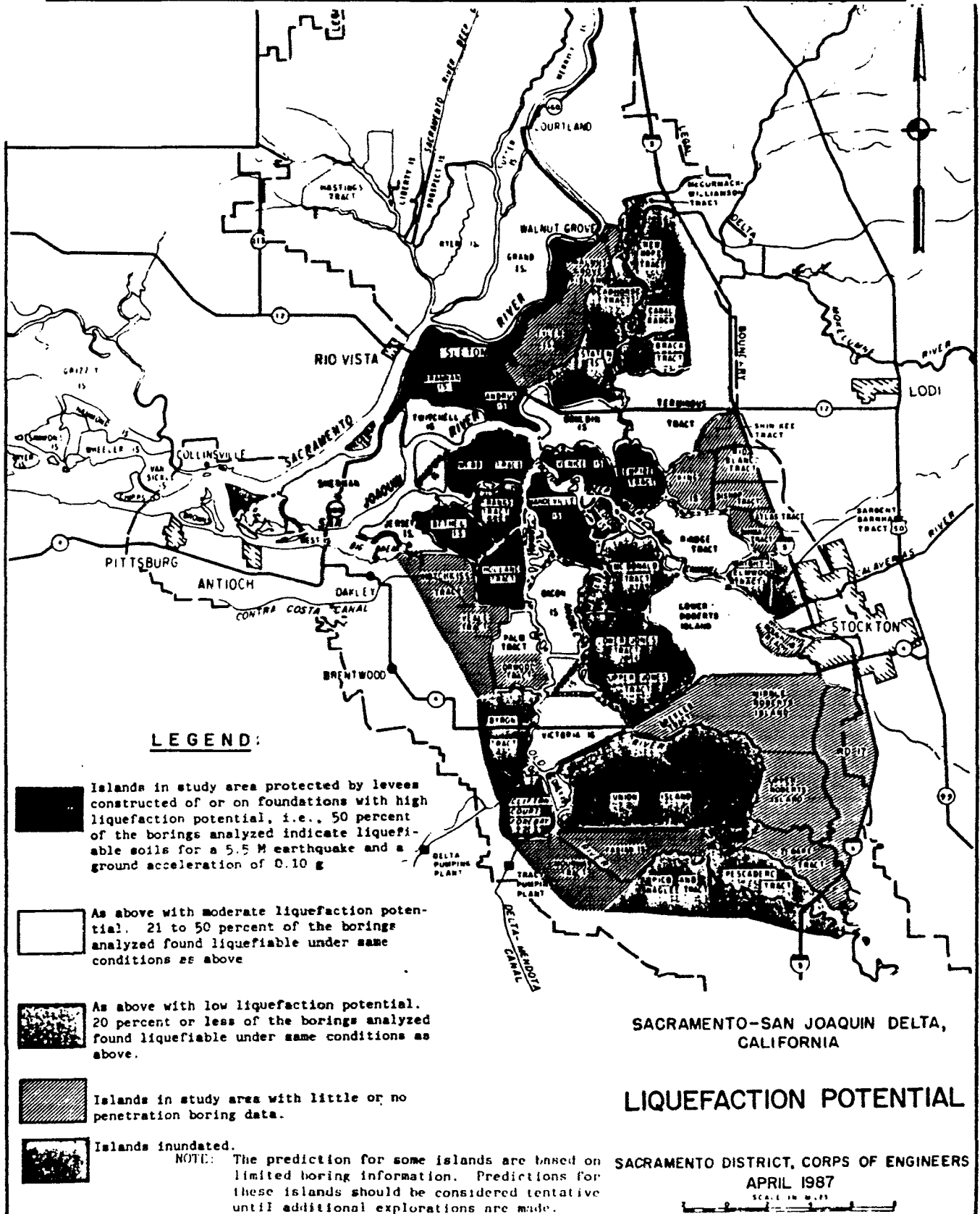


FIGURE 11: LIQUEFACTION POTENTIAL (from USACE, 1987)

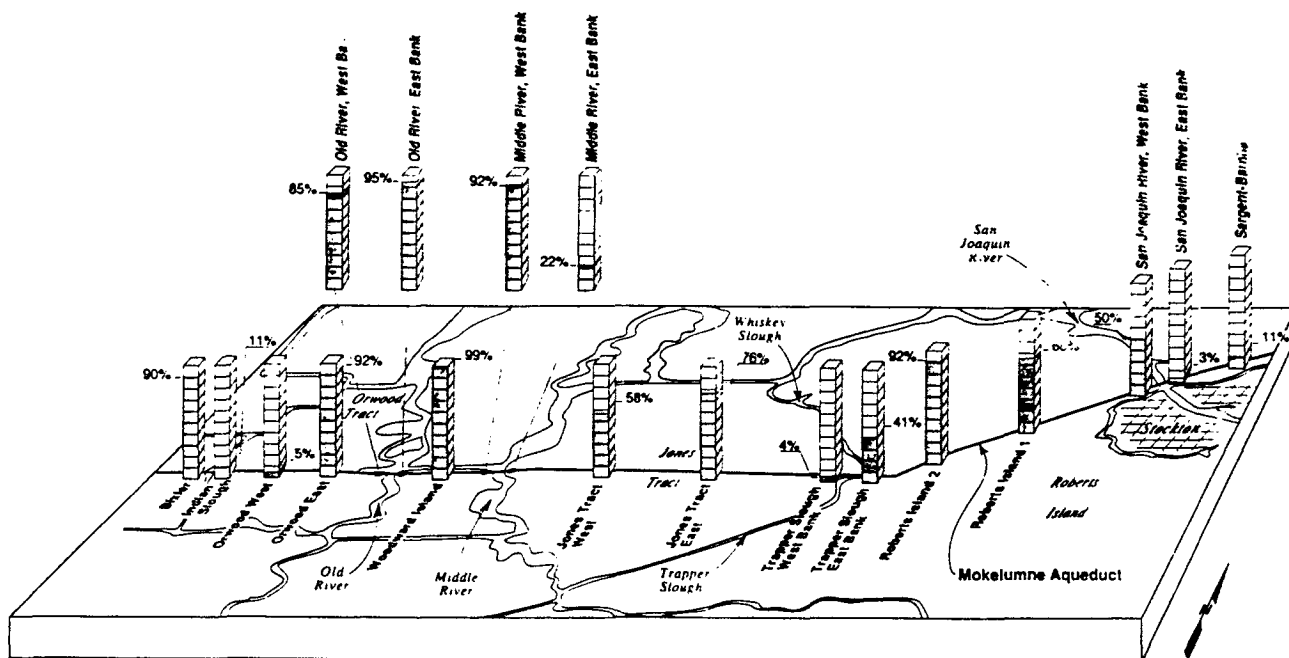


FIGURE 12: PROBABILISTIC LIQUEFACTION POTENTIAL (from Earth Sciences Associates, 1992)

## 6. PRELIMINARY ASSESSMENT OF LEVEE DAMAGE POTENTIAL

### 6.1 GENERAL

Precise predictions of performance for the vast levee system in the Delta during future earthquakes are not possible with the information available. With hundreds of miles of levees, variable geometries, variable levee materials, and variable foundations, the problem is simply too large and the information too incomplete to be conclusive for specific reaches. However, some insight can be gained by assuming a general level of behavior for levees, and to examine the potential for different levels of earthquake shaking to affect performance. To this end, the following criteria were used in delineating potential levee damage susceptibilities:

HIGH - It is likely that there would be widespread liquefaction of sandy and/or silty levees, probably resulting in sufficient losses of freeboard to cause overtopping and subsequent inundation of the island or tract. Extensive cracking leading to piping failures of the levees is also expected to be common in this area.

MODERATELY-HIGH - It is likely that isolated reaches of levees would develop extensive liquefaction and result in significant loss of freeboard. In such areas where levees also have relatively little freeboard and/or limited cross sections, overtopping and piping failures are likely.

LOW to MODERATE - Liquefaction of levee embankments may occur intermittently. In many locations there may be localized slumping and cracking similar to that which occurs during large floods. Levee failure may result if repairs are not made immediately.

LOW - Locations of liquefaction within levees are sparse and difficult to detect. Minor cracking and slumping may be reported. However, it will be difficult to ascertain whether they were pre-existing or a result of the earthquake. Some pre-earthquake seeps may change flow rates, or may even stop flowing. No major repairs would be expected as a result of the earthquake shaking.

## 6.2 PRELIMINARY ASSESSMENTS OF LEVEE DAMAGE POTENTIAL

Preliminary assessments of levee damage potential during future earthquakes are shown in Figures 13 and 14. The assessments were developed using the probabilistic bedrock accelerations shown in Figure 8 for a 30-year exposure period. Two alternative assumptions for ground motion amplification were used. In Figure 13, an amplification factor of 1.0 was assumed. In Figure 14, an amplification factor of 1.6 was used. These values represent our best estimates for ground motion amplification for Delta deposits and were derived from seismic response analyses and the past performance of the levee system.

The estimated zones of levee damage potential are not intended to imply that all levee reaches in the zones have the same susceptibilities. Rather, it is expected that at least some portions of each levee reach will have sufficiently liquefiable material to result in the susceptibility identified.

The preliminary assessments indicate that only the westernmost portions of the Delta have a moderately high probability of experiencing levee damage within 30 years if an amplification factor of unity is assumed (see Figure 13). However, if the amplification factor was increased to 1.6, the entire western half of the Delta is shown to have a moderately high susceptibility to levee damage (see Figure 14). The two plots together describe our current perception of the probable range in susceptibility for a 30-year exposure period. Although Figures 13 and 14 show that the western edges of the Delta appear to be vulnerable to future earthquake shaking, it should be noted that this assessment is not as pessimistic as other studies (e.g. see Figure 12). For higher exposure periods (e.g. 50 years or 100 years), the expected susceptibilities for levee damage and failure significantly increase.

## 6.3 DAMAGE POTENTIAL FOR EIGHT KEY WESTERN DELTA ISLANDS

Preventing the inundation of eight key western islands in the Delta is considered important in preventing salt water intrusion in the Delta. These eight islands are located on the most western portions of the Delta and are Sherman Island, Twitchell Island, Bradford Island, Jersey Island, Hotchkiss Tract, Webb Tract, Bethel Tract, and Holland Tract.

Unfortunately, their western locations also mean that they would probably be exposed to the highest levels of base

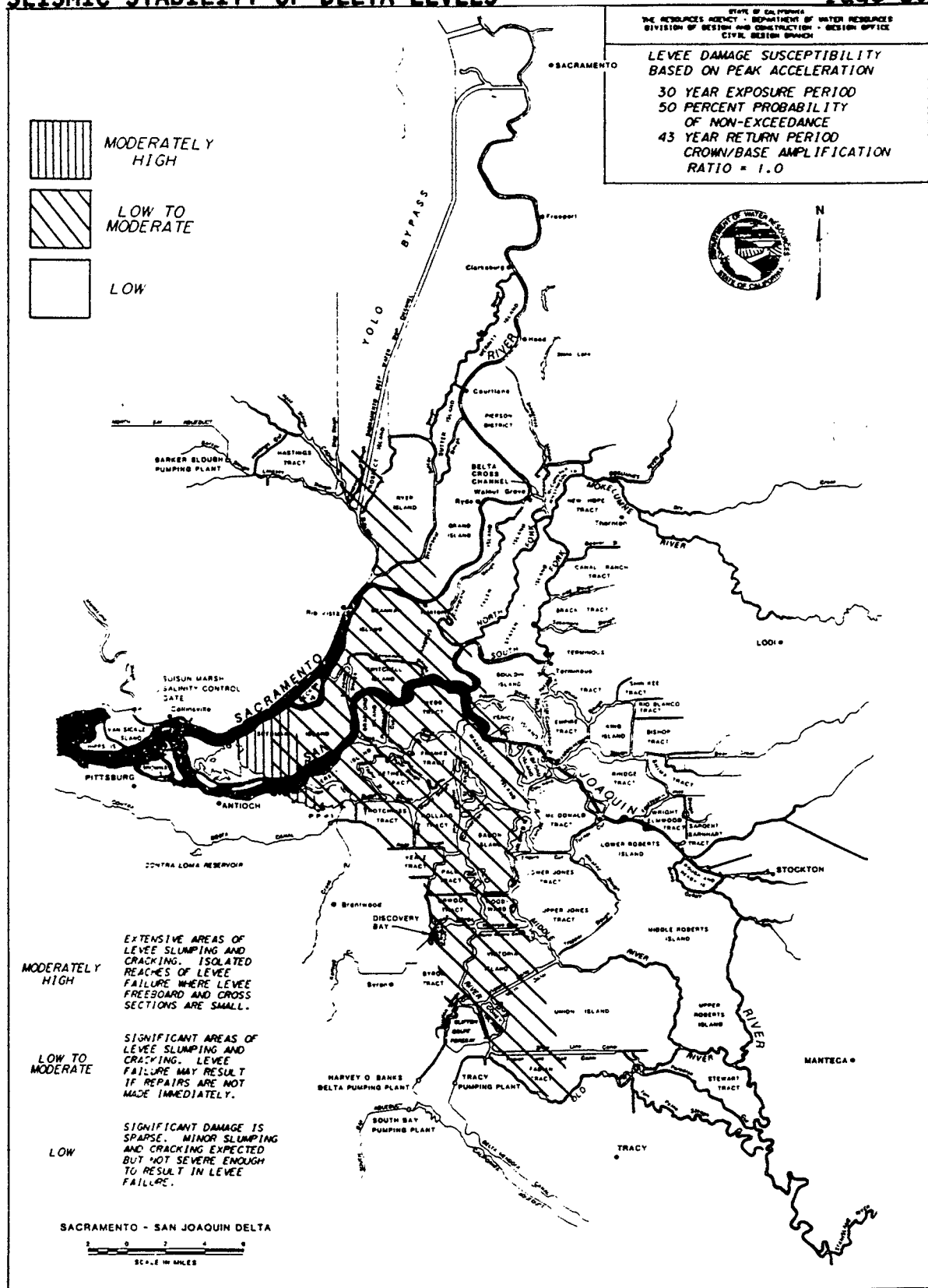


FIGURE 13: ESTIMATED LEVEE DAMAGE SUSCEPTIBILITY  
(Crown/Base Amplification Factor = 1.0)

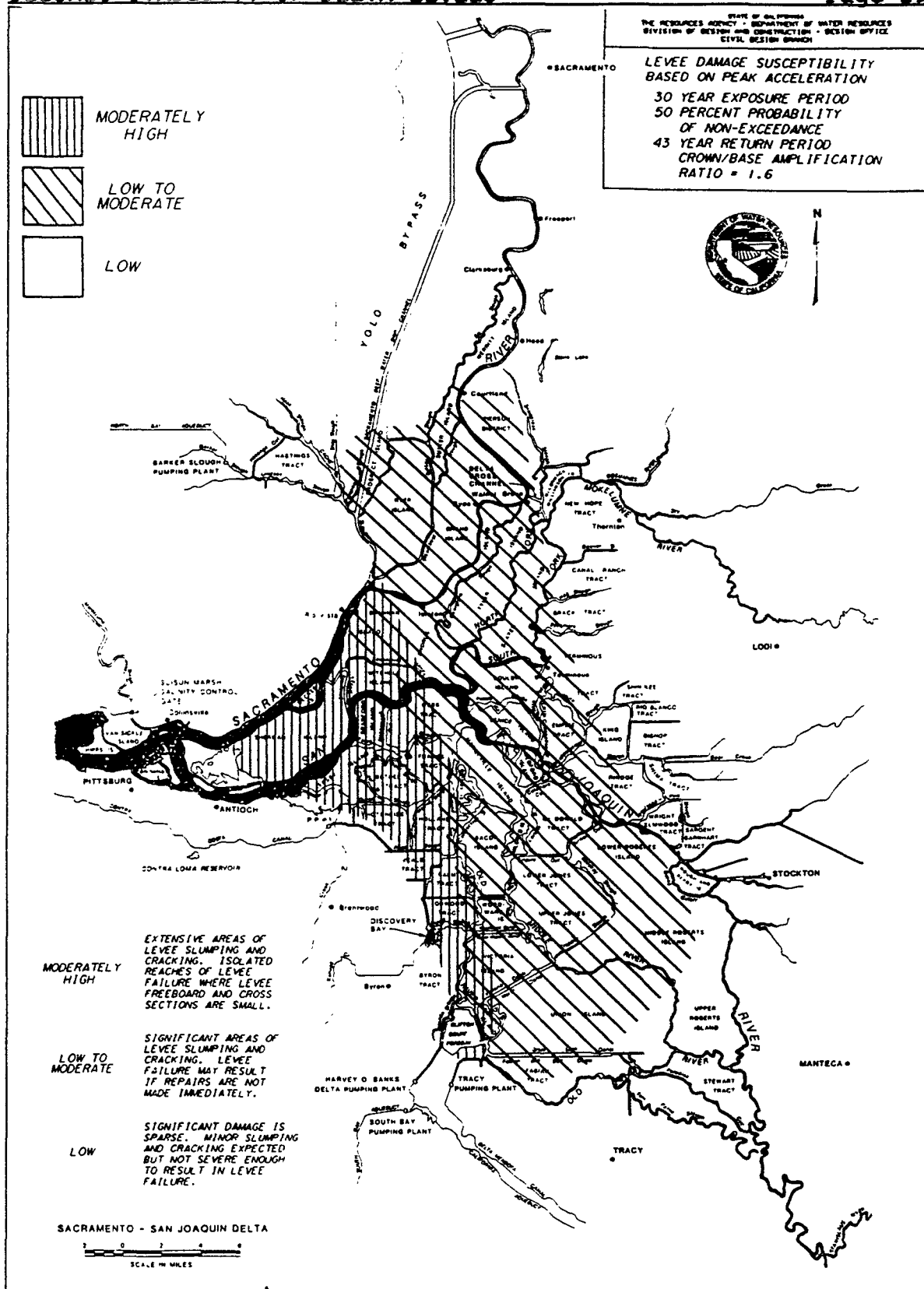


FIGURE 14: ESTIMATED LEVEE DAMAGE SUSCEPTIBILITY  
(Crown/Base Amplification Factor = 1.6)

motion that the Delta might experience from future earthquakes. As stated previously, the western edge of the Delta is expected to experience higher levels of shaking due to the fact that the earthquake sources are generally located to the west of the Delta. The estimated damage susceptibilities plotted in Figures 13 and 14 reflect this result. Even for the lower amplification factor (i.e. amplification factor equals 1.0), Sherman Island is shown to be susceptible to moderately-high damage (see Figure 13). For the higher ground motion amplification shown in Figure 14, all of the eight key western islands are shown to be susceptible to moderately-high damage within the next 30 years.

Supporting this result is the 1987 U. S. Army Corps of Engineers evaluation of liquefaction potential showing that seven of the eight key western islands have a moderate to high potential for developing liquefaction (see Figure 11).

#### **6.4 METHODS AVAILABLE TO STRENGTHEN LEVEES AGAINST EARTHQUAKES**

Methods available to strengthen levees against earthquakes include the following:

- o In situ densification by vibrating probes or grouting to prevent liquefaction and strength loss. These measures are extremely expensive and are generally economically feasible only for limited reaches.
- o Increase the size of levees to increase stability and maintain freeboard in case of earthquake-induced settlement. This approach requires staged construction techniques and the addition of a substantial amount of fill which is already in short supply in the Delta.
- o Installation of cut-off walls and/or filters to mitigate the effects of cracking and internal erosion. This is also relatively expensive, but not as high as in situ densification.

Due to the long lengths of levees associated with each island, typically several miles, it probably is not economically feasible to remediate most levees to resist seismic shaking. At most, some key or extremely weak levee reaches might be treated. However, even the investigations required to determine which reaches are the worst and what type of treatment would be required could cost several million dollars for each island. This would be a separate cost from the actual treatment.

## 7. FUTURE STUDIES

### 7.1 PURPOSE AND NEED

It has not been the intention of the Department's seismic evaluations to either identify specific levee reaches for remediation, or design new levees to meet earthquake standards generally associated with dams. It is unlikely that most levee reaches can be economically upgraded to meet such criteria. Rather, the purpose of the seismic stability evaluations performed to date has been to develop information as to the susceptibility and opportunity for Delta levees to sustain damage during earthquakes. With this information, the degree of risk can be estimated in a general way and a rational approach can be pursued in the management of existing and future Delta facilities and resources.

During the course of the Department's preliminary evaluations, it became evident that it would be difficult to carry out seismic evaluations due to the numerous unknowns which could significantly influence the results. The unknowns which were identified as having the largest effects on assessments of levee stability during earthquakes are listed below in descending order of importance:

- A. Amplification/damping characteristics of shallow organic soils.
- B. Liquefaction resistance of levee fills.
- C. Strength loss potential in cohesive/organic soils following earthquake shaking.
- D. Amplification/damping characteristics of deep soil profiles.
- E. Liquefaction resistance of foundation soils.
- F. Probability of Coast Range-Sierra Nevada Fault Zone producing a large magnitude earthquake (M~6.5) within the Delta.

Several previous studies have also identified some of the above areas as requiring additional study. By far the most important is to determine the potential for Delta soils to either amplify or dampen out earthquake motions.

## 7.2 INSTALLATION OF SURFACE AND SUBSURFACE SEISMOGRAPHS

The Department is proceeding to install suites of surface and subsurface seismographs at four sites in the Delta to measure earthquake motions as they propagate through the soils beneath and through Delta levees. A typical suite of seismographs is shown in Figure 15, depicting three subsurface instruments beneath the levee at various depths together with a surface instrument on the levee crown. A schematic of the surface installation is also shown. The subsurface instruments will be installed in boreholes. Figure 16 shows the locations of the four downhole seismograph sites. Also shown are the locations of existing Department of Water Resources surface instruments located within and along the edges of the Delta.

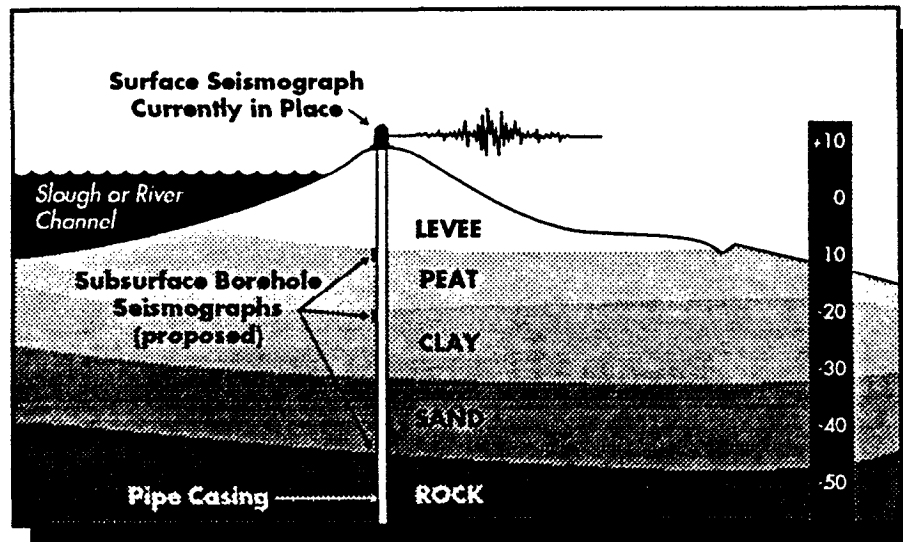
The purpose of the seismographs will be to use data obtained during small or distant earthquakes to predict performance of levees and other structures during larger or closer earthquakes. The data obtained will be used to:

- o Document characteristics of the earthquake motion.
- o Assess the ability of soft, organic soils in the Delta to amplify or dampen earthquake motions.
- o Calibrate the performance of levees and structures with different levels of earthquake motion.

Between 1979 and 1989, there were four earthquakes that would have yielded significant information had there been such instruments installed in the Delta. Since regional seismicity is not expected to diminish during the 1990s, it is reasonable to expect that, within 10 years, an earthquake will occur sufficiently close to provide such information. The installations are expected to be complete by February 1994 and the instruments are planned to be maintained for at least 10 years.

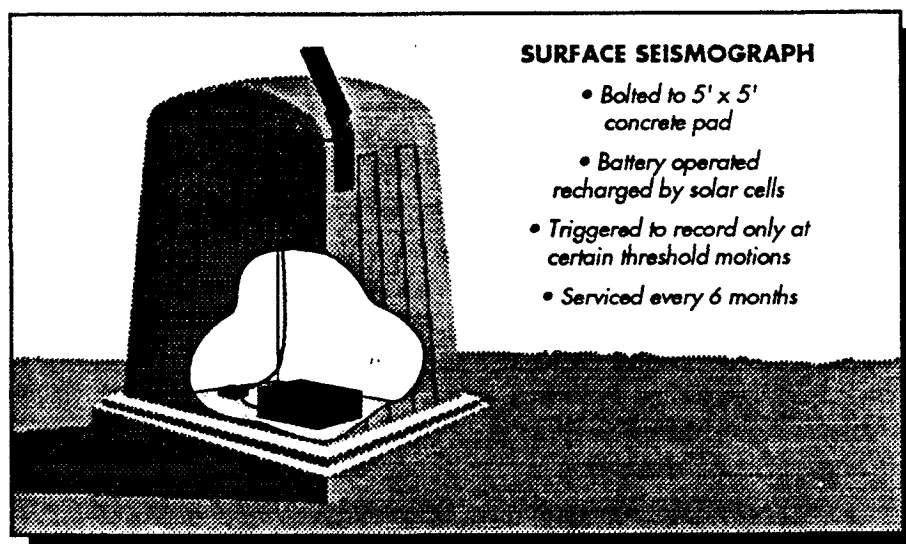
## 7.3 LABORATORY AND FIELD TESTING OF ORGANIC SOILS

In addition to the installation of seismographs, a limited program for investigating the dynamic properties of organic soils will be done concurrently with the placement of the instruments. Similar investigations have lead to the development of material properties characterizations which can be used analytically to predict behavior. For example, it is

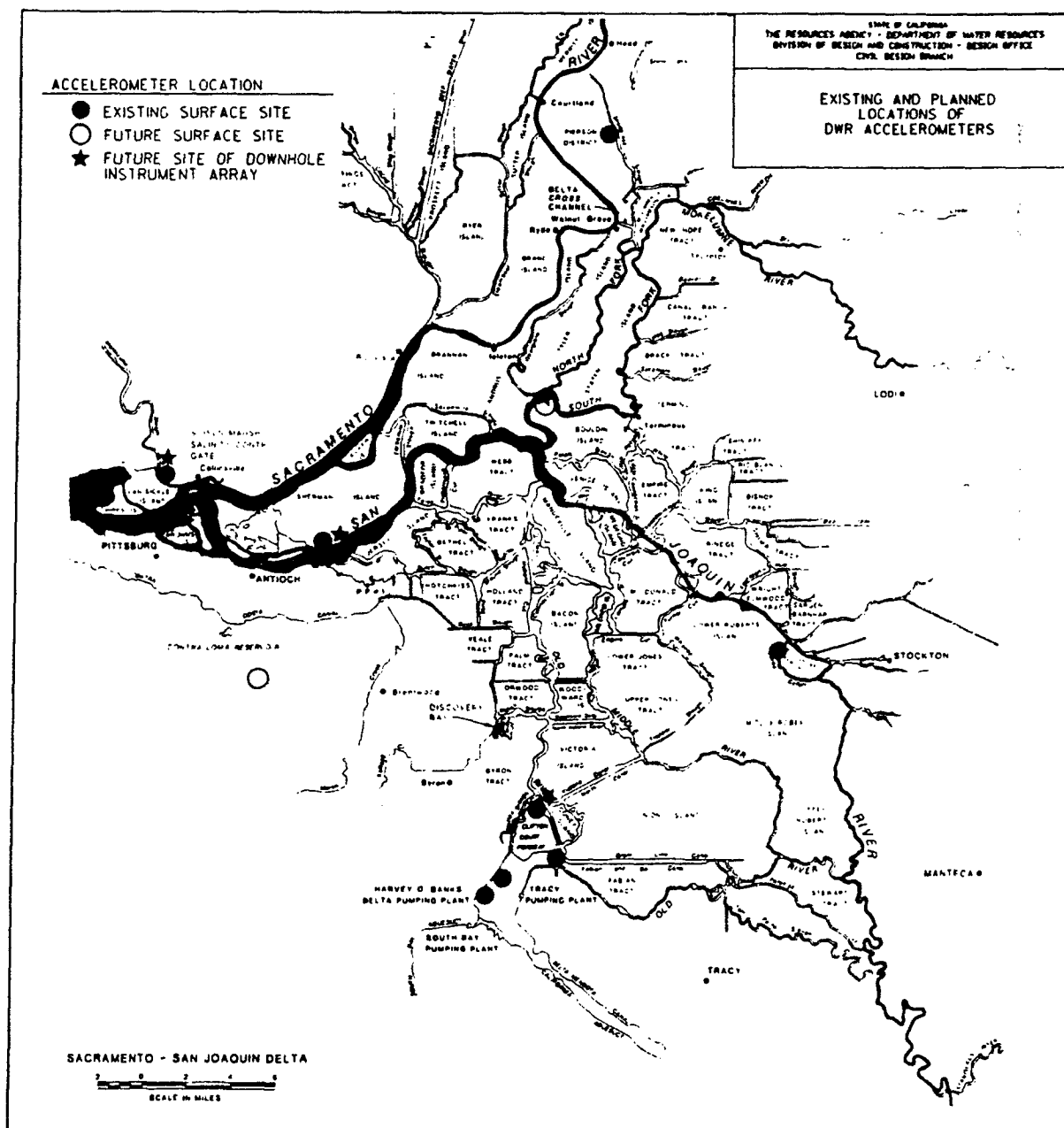


The basic purpose of the seismic instrumentation is to use data obtained during small or distant earthquakes to predict performance of levees and other structures during larger or closer earthquakes. The data obtained will be used to:

- Document characteristics of the earthquake motion.
- Assess the ability of soft, organic soils in the Delta to amplify earthquake motions.
- Calibrate the performance of levees and structures with different levels of earthquake motion.



**FIGURE 15: SCHEMATIC ILLUSTRATION OF SEISMOGRAPH INSTALLATION PLANNED FOR DELTA LEVEES**



Instrument Location	Date Installed	Site Conditions
Peripheral Canal	1969	Alluvium
Delta Pumping Plant (2 devices)	1971/1973	Structure founded on rock
Calif. Aqueduct Milepost 1	1980	Canal cut slope in rock
Rough and Ready Island	1980	Structure founded on levee
Clifton Court Forebay	1983	Spoil fill over alluvium
Clifton Court Forebay - North Levee	1991	Levee overlying peaty soil
Sherman Island - South Levee	1991	Levee overlying peaty soil
Montezuma Slough - East Levee	1991	Levee overlying peaty soil

FIGURE 16: LOCATIONS OF EXISTING AND PLANNED SEISMOGRAPH SITES IN THE SACRAMENTO-SAN JOAQUIN DELTA

now possible to predict with computer programs the ground motion amplification which occurred along the margins of the San Francisco Bay during the 1989 Loma Prieta Earthquake. However, this required over 20 years of experience to develop such material characterizations.

The laboratory and field investigations currently scheduled by the Department will be of limited scope. These investigations are associated with the installations of the downhole seismographs and no strain-dependent dynamic properties will be developed under this program. However, the Department is investigating possibilities of conducting more extensive joint investigations with other agencies and universities. Such studies could include field and laboratory testing which would develop strain-dependent dynamic properties such as modulus degradation and damping characteristics. The development of such material characterizations could lead to more accurate predictions of ground motion amplification which would be very valuable when used in conjunction with the results of the anticipated seismographic data.

**DELTA LEVEE AND CHANNEL  
MANAGEMENT ISSUES**

**DELTA LEVEE AND CHANNEL REPAIR  
AND MAINTENANCE ISSUES**

**Prepared by: BDOC Staff**

**Assisted by: Frank Wernette, Department of Fish and Game  
Anna Hegedus, Department of Water Resources  
Ed Littrell, Department of Fish and Game**

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# **DELTA LEVEE AND CHANNEL REPAIR AND MAINTENANCE**

## **INTRODUCTION**

The purpose of this paper is to describe some of the issues surrounding levee and channel management in the Delta and the inherent conflicts which arise between retaining and restoring fish and wildlife habitat on levees and maintaining those levees for flood protection. The principal catalyst for this disagreement over levee values has been the Delta Flood Protection Act of 1988 (SB-34) program for levee repair and maintenance and thus an overview of the SB-34 program and its implementation is presented here. The fish and wildlife values associated with the Delta's levees and the channel system defined by these levees, and the wildlife values protected by the Delta's levees are also described in the appendix to this paper.

This paper deals mainly with "non-project" levees, that is, levees which are not part of the Sacramento Flood Control Project constructed by the U.S. Army Corps of Engineers. While the issues are similar, the following discussions do not in all cases apply to the "project levees" - although wildlife resource managers express similar concerns over the way that many of the issues discussed in this paper are addressed for the "project levees".

SB-34 allocated \$120 million - 12 million per year from 1988 through 1997, for two program components addressing "non-project" levees. These components are the Special Flood Control Projects for the eight western Delta Islands (\$6 million per year) and the Delta Levee Subvention Program (\$6 million per year). These programs are discussed in more detail later in this paper.

"Non-project" levees are maintained, repaired, and upgraded by local reclamation districts in accordance with the States Flood Hazard Mitigation Plan (FHMP) for the Sacramento-San Joaquin Delta. Portions of the cost for implementing the plan are eligible for reimbursement through the SB-34 program (up to 75% for maintenance and rehabilitation and up to 100% for mitigation work). In contrast, "project levees" are maintained under separate funding sources by Reclamation Districts or by the State of California, Department of Water Resources, under agreement with the Corps of Engineers, according to standards set forth in separate federal legislation.

Efforts by levee districts and other agencies throughout the Delta have historically focused on protecting farm land, homes, urban areas, and other public developments such as highways, railroads, and major aqueducts. Until recent years little attention was paid to how these efforts affected fish and wildlife and their habitat. As a result of the environmental

mandates expressed in SB-34 and SB-1065 - which directed that the Department of Fish and Game determine that any project funded under the program will not result in a net long term loss of habitat - the impacts of levee and channel work on fish and wildlife resources have taken a much higher profile.

Efforts to maintain and develop high value wildlife habitat on the levees is considered by many levee maintenance managers a threat to the structural integrity of Delta levee systems and it is considered by others to be a barrier to routine inspection and maintenance of the system. Further, during floods the dense vegetation - which is an important part of high value habitat - can obstruct an effective flood fight effort. Despite the disagreement over the emphasis which should be placed on flood protection versus wildlife habitat, there seems to be general agreement to the benefits of protecting the Delta islands and their valuable wildlife values.

The components of these issues are the subject of the remainder of this paper.

## LEVEE AND CHANNEL MAINTENANCE ISSUES

### Dredging

The potential exists for dredging activities to result in local, temporary adverse impacts on Delta channel water quality. These impacts may include the potential release of toxic pollutants into the surrounding water, where dredging occurs adjacent to marinas. While there always is a slight potential for these impacts to occur during levee maintenance and repair projects, there have not been any identified problems of this nature to date as a result of SB-34 sponsored projects.

Temporary reduction in dissolved oxygen levels resulting from increased organic matter (which absorb oxygen for decomposition) and increased turbidity levels are also potential impacts which may occur during dredging activities. The severity of these impacts if any, depends on the location, construction method, and time of year. Eggs and larvae of fish such as longfin smelt, delta smelt, and striped bass, which may be present between January and July, are generally more susceptible to these adverse environmental conditions than adult fish.

While both fishery resource managers and levee maintenance managers seem to agree that these potentials exist, some levee maintenance managers observe that there have not been any documented cases in the SB-34 program to date and question whether the threat is overstated.

Concerns about the potential of adversely impacting species listed under the Endangered Species Act has resulted in a severe limitation on dredging activities. As a result, dredging has been limited to principally the months of July and August thus effectively limiting the construction season to 60 days for levees which require work in the channels. Fisheries data is currently being collected to better define critical periods and location so that consideration can be given to expanding this dredging window. Until this is completed, there is a significant risk that fill material from dredging will not be available to maintain and restore levees.

Concerns have also been expressed by fisheries resource managers that if current dredging techniques which avoid work at the levee toe are abandoned there is a potential that dredging and other bank stabilization projects (i.e. riprapping) may result in the direct loss of habitat for young chinook salmon and their prey. These impacts result from removing aquatic vegetation, dead branches and snags and "shaded riverine aquatic habitat" from the toe of the levees. While there have not, to date, been any instances of such direct loss as a result of dredging activities carried out by projects administered under SB-34, fishery resource managers believe that continuing attention by levee maintenance managers needs to be applied to protecting these aquatic habitats for all projects.

## Levee Maintenance Activities

Prior to the development of more recent levee management techniques, conflicts between maintaining levees and sustaining wildlife habitat on levees seemed to be inevitable. The Delta levees provide and protect important wildlife habitat for numerous species. Important riparian habitats are found on the water and land side of the levees and berms.

Installation of revetments and riprap typically requires the removal of vegetation from maintenance sites. Fishery resource managers have voiced concerns over the potential that removing streambank vegetation and preparing the banks for protective materials may release organic matter to the stream system and increase turbidity levels. If this elevated level of organic matter occurs there is a potential that smothering of fish and eggs and larvae downstream or upstream (depending on tidal flow conditions) could occur. It is also possible that reduced dissolved oxygen (DO) levels, impacting both fish and larvae could occur. There have not been any observed occurrences of high turbidity levels or reduced D.O levels associated with the SB-34 projects, however, it is important that levee repair and maintenance project managers be aware of the potential and continue to take steps to avoid these impacts.

Levee maintenance managers are concerned that uncontrolled levee vegetation on levees is a potential hazard. They believe that trees with extensive root systems can create paths for the piping of water through the levee, potentially leading to levee failure. Some trees are subject to being toppled by wind, taking large segments of the levee with them in their fall. Dense foliage or undergrowth can obscure the visibility of the levee face and impair inspection of the levee. Dense vegetation may also present an obstacle to emergency flood fights, further exacerbating the threat of flooding.

Some wildlife, including beavers, muskrats, and ground squirrels, can pose a direct threat to levee stability. As with vegetation, the degree of threat varies with the location and species. Between wildlife resource managers and those responsible for maintaining Delta levees there are differing opinions and observations as to whether the threat is real or more a perception of a threat. A significant difference of opinion revolves around allowing certain types of vegetation to grow on levees (particularly fruit and nut producing plants).

Most levee maintenance managers observe that these types of plants attract animals whose colonies and burrows weaken levees and tend to induce water through the levee. Dense levee vegetation can act as barrier to visual detection of burrowing rodent colonies. Many levee maintenance managers consider that biological control methods proposed by some resource managers for controlling burrowing rodents on levees are not effective due to their zero tolerance threshold for these animals in levees. They observe that biological control measures (such as introduction of predators and vegetation management) may assist in population reduction but is not generally acceptable to levee maintenance managers as the single control method. Where this method is utilized it is generally part of an integrated approach also employing chemical control methods where the biological methods are not 100% effective.

In contrast, many wildlife resource managers believe that recent evidence demonstrates that frequent stripping, burning, mowing, grazing, or other practices which create large areas of sparse vegetation actually encourage rather than discourage ground squirrel populations. Approaches to biological management of ground squirrel colonies are under study which include increasing vegetative cover for predator hiding and perching. They believe that these methods would encourage natural predators of the ground squirrels, gophers, and other rodent pests, thus controlling this problem naturally. However, progress has been slow in documenting the value of these methods and developing acceptance among those responsible for levee maintenance for the reasons cited above.

There seems to be general agreement that the burrows of beavers and muskrats are a problem. In an undisturbed setting, these animals construct lodges in marshlands and dig burrows in wide riverside berms where food is plentiful and they are relatively isolated from predatory animals. Channel banks may also be used, but are generally a less secure location. In the Delta, available habitat for these animals is scarce, and while they do use marshlands and berms to the extent they are available, they also burrow into unriprapped banks. Beavers burrows weaken levees and can lead to levee failure.

The paragraphs above summarize some of the resource conflicts and the disagreements over the priority of safety verses fish and wildlife resources which typify the Delta levee and channel maintenance programs. While considerable progress has been made toward resolving the conflicts and disagreements since the start of the SB-34 program, there still remains some issues to resolve. The following section describes some of the initiatives which are underway to address the remaining issues.

## **CURRENT INITIATIVES TO ADDRESS THE DELTA LEVEE AND CHANNEL CONCERNS**

Innovative programs to address these levee concerns are being developed and implemented at both the State and local level.

These initiatives are being pursued in recognition of the habitat value of the levee system and represent active attempt to protect fish and wildlife values while still maintaining appropriate levels of flood protection.

These initiatives include programs for levee maintenance activities and for dredging activities.

### **Levee Maintenance Activities**

Proposed vegetation guidelines are being developed for local levees that will emphasize the retention of certain vegetation types and provide for vegetation mitigation and enhancement. The establishment of these vegetation types on levees has not historically been endorsed by the SB-34 program. The proposed vegetation guidelines will be in accordance with the Hazard Mitigation Plan (HMP).

Two demonstration slope protection projects have been implemented as part of the SB-34 program using materials other than riprap. These materials were chosen due to their potential to accommodate substantial vegetation regrowth while providing protection from erosion. Several hundred feet of Armoflex and Tri-Lock articulating blocks were placed on some Delta levees in 1993. DFG planted riparian vegetation on the sites and is monitoring the regrowth. This erosion protection method is two to three times more expensive than riprap, therefore its use may be limited.

Most reclamation districts strongly believe that riparian vegetation can be easily and inexpensively reestablished on riprap. Vegetation on riprap will grow naturally, without any planting effort. Current maintenance practices however do not allow vegetation to establish on riprap for reasons discussed earlier. The new vegetation management guidelines if approved and implemented may result in a significant cumulative enhancement of riparian vegetation over existing conditions in the Delta.

Innovative projects such as the water side berms project at Staten Island discussed later in this paper and DWR's proposed levee improvement project at New Hope Tract and Grizzly Slough are good examples of recent initiatives to improve flood protection while preserving or creating riparian and wetland habitat.

## **Dredging Activities**

Fish exclusion devices such as curtains, nets, and sound barriers are being studied for use in keeping fish from entering the sites where clamshell dredging is occurring. If fish can be excluded from the work area, then dredging may be able to take place at any time of the year without creating impacts on aquatic "species of concern". Turbidity control has been used as an element of dredging activity to protect the eggs of delta smelt when the smelt are developing in adjacent shoaling areas. In addition, the use of clamshell dredges instead of hydraulic dredges can greatly reduce adverse impacts from dredging operations.

In order to understand better and define the distribution of salmon and Delta smelt in the Estuary during the year, data are being collected, analyzed and mapped in an attempt to define the seasonal distribution of salmon and smelt in the Delta. It is possible that these distribution maps will document longer periods of time in which minor dredging may be permitted in certain regions of the Delta without impacting these fish. Any broadening of the dredging window will be incorporated into DFG's 1601 Agreements for SB-34 work.

## **Interagency Coordination**

The Resource Agencies' Delta Levee and Habitat Advisory Committee is working to:

1. Streamline Permits for Levee work in the Delta.
2. Explore the utility of Habitat Conservation Plans (HCP)
3. Provide Guidance on Habitat Mitigation Programs

A Subcommittee has developed options for better coordinating and streamlining the various regulatory actions by State agencies affecting delta levees. Resource Agency staff has also recently opened discussions with the Army Corps of Engineers and the Fish and Wildlife Service to secure a General Permit for levee work done pursuant to the SB-34/1065 programs. Other jurisdictional agencies will be encouraged to follow suit with program-wide permits/agreements for levee work that does not result in a net long-term loss of habitat.

The Advisory Committee will also explore the development of conservation plans to meet the requirements of the State and federal endangered species act. The goal will be to plan for the needs of listed species and their habitats while also allowing levee maintenance work to proceed.

The Department of Fish and Game will soon release its "Mitigation Guidance Document", a handbook for levee districts and landowners to assist them in developing habitat mitigation projects for levee maintenance. The document will endorse the use of mitigation banks for many of the common impacts to habitat on delta levees. These banks will both enhance the overall habitat quality and biodiversity in the delta, as well as provide additional options for levee districts to mitigate the site specific loss of habitat.

## **LEVEE REPAIR AND MAINTENANCE ISSUES AND IMPLEMENTATION OF THE SB-34 PROGRAM**

The Delta Flood Protection Act of 1988, also referred to as SB-34, was enacted to facilitate accomplishing the traditional goals of Delta levee maintenance with enhanced state funding of these activities (Delta Levee Subventions Component) and to restore significantly degraded levee systems on New Hope Tract and eight key west Delta islands such as Twitchell Island, Webb Tract, and Sherman Island (Special Flood Control Project Component). Concurrently this program addresses the Delta's fish, wildlife, and plant resources most often affected by levee maintenance and restoration activities. The most significant component of the legislation from the fish and wildlife perspective is the mandate that levee maintenance and restoration activities partially reimbursed by SB-34 would not result in a net long-term loss of riparian, fisheries, or wildlife habitat. The DFG is required to make a finding to that effect before state reimbursement funds are disbursed.

The interagency coordination and district cooperation required to implement the subventions component of SB-34 (which reimburses portions of the maintenance costs incurred by local reclamation districts) has developed slowly reflecting both misunderstanding about implementation and some reluctance by reclamation districts to modify their levee maintenance permit acquisition practices. Many reclamation districts questioned DFG's jurisdiction in application of Fish and Game Code Section 1601, stream alteration agreements, to the SB-34 work. Others were concerned that funds needed to implement mitigation to ensure "no net long term loss" would reduce funding for badly needed levee maintenance and restoration. In follow-up legislation (SB-1065) the legislature provided specific guidance to the Resource Agency on how the environmental mitigation portions of the program - as well as other parts of the program - were to be implemented. Beginning in the fall of 1991 the persistent efforts of the reclamation districts, assisted by Department of Water Resources (DWR) and DFG staff, to implement the mandates of SB-1065 have resulted in progress towards meeting the habitat conservation goals originally posed in SB-34.

As an illustration of the degree of acceptance that the environmental goals of SB-34 have achieved among the reclamation districts, consider the following example of a local reclamation district. While not choosing to participate in the SB-34 program, the local reclamation district nevertheless took the initiative, in cooperating with DFG and DWR staff in designing and installing waterside berms to improve shaded river aquatic habitat and emergent wetland and riparian adjacent to Staten Island. Efforts such as these are an important step in searching for ways to improve fish, wildlife, and plant habitats using approaches compatible with levee and channel maintenance.

While the efforts to resolve the competing priorities between providing flood protection and preserving fish and wildlife habitat have occupied center stage to date, there is a larger issue of program funding looming on the horizon. SB-34 authorized \$12 million of annual funding each year through 1997 subject to specific budget authorization. This authorization covers the combined work of the Special Flood Control Projects (\$6 million) and the Subvention

Program (\$6 million) which reimburses local reclamation districts for their work. It should be noted that the Subventions Program component funding was less than the \$12 million authorized in 1991-92 and fell to \$2 million in the 1992-93 fiscal year budget.

The SB-34 funding will expire at the end of Fiscal Year 97-98. While the program will have significantly contributed (\$120 million) to addressing some of the most urgent levee problems, the many public values dependant upon sound levees will still be considerably at risk. The magnitude of this risk can be seen from the Army Corps of Engineers' report in the early 1980's which estimated in excess of \$1 billion of needed Delta levee rehabilitation.

Funding in the amount of \$3 million was provided to the Department of Fish and Game as part of SB-1065 to fund mitigation programs to offset for impacts incurred in the early years of the SB-34 program. DFG is currently in the process of identifying projects for this mitigation program, however progress has been slowed by the difficulties in finding riparian and aquatic habitats which will serve as offset for those impacted by the levee work. The legislation specifically state that the mitigation funds had to be expended by June 30, 1994 or the appropriation would revert and be lost to future mitigation work.

When the funding authorized by SB-34 expires in 1997, full funding for levee maintenance work will revert back to the local reclamation districts, in the absence of additional legislation addressing that issue.

## CONCLUSION

While the implementation of levee projects in the early years of the SB-34 program may have produced serious conflicts with fish and wildlife resources, the recent successful implementation of some programs suggests improved future effectiveness for the SB-34 program. With continued attention to the principles developed in these recent programs, future levee maintenance efforts should result in the maintenance of the Delta's levees and channels in a manner which concurrently protects fish, wildlife, and plant resources while also recognizing the environmental values on the islands protected by the levees.

Protecting the existing flood control and habitat values of the levees and the islands they protect while pursuing a goal of regaining some of the fish and wildlife habitat and aesthetic qualities which have been lost in the Delta is the challenge. Success in meeting the challenge will require that restorative and enhancement programs be implemented while applying present resource management practice to ongoing maintenance activities. Recent levee maintenance and design techniques maximize the avoidance of impacts on habitat and emphasize the natural retention of riparian vegetation while also allowing levee maintenance activities to continue. These techniques are only now being documented. Over the next few years it will become more apparent whether these techniques will accomplish the positive results that they promise.

While significant progress has been made toward stabilizing and improving the flood protection afforded by Delta levees, the challenge of the future lies in securing funding to continue this effort past the 1997 expiration of SB-34 funding. Innovative funding techniques need to be explored in order to secure financial participation by all parties that benefit from the protection afforded by the Delta levees.

## Appendix

### FISH AND WILDLIFE VALUES ASSOCIATED WITH THE DELTA'S CHANNEL AND LEVEE SYSTEM

The Delta levees provide and protect important wildlife habitat for numerous species of waterfowl and other wildlife. The Delta channels defined by that levee system also support fishery resources of state, national, and international significance. These habitats support:

- 230 species of birds,
- 45 species of mammals,
- 52 species of fish,
- 25 species of reptiles and amphibians,
- 150 species of plants.

Two categories of fish and wildlife habitat are integral to discussions of Delta levees. First, are the habitats associated with the levees themselves and second, those habitats on the island interiors that are protected as a by product of levees. Both categories of habitat contribute to the Delta's fish and wildlife values.

The extent of the marshes, riparian forests and other habitat types in the Delta as it existed before human intervention is not precisely known. However, based on historical accounts and other available data, it is possible to generally characterize the historic condition of the 700,000 acres in the Delta. The heart of the Delta was likely covered primarily by tidal freshwater marsh, crisscrossed by many waterways, including dead-end sloughs. Riparian was only a small component of the habitat composition. Large rivers and streams, entering the outer Delta on the north, east and south created waterways which were bordered by extensive stands of riparian forest growing on naturally deposited alluvial levees. The area also contained upland grasslands and woodlands.

In the Central Valley as a whole, more than 90 percent of the riparian forest is gone. They were cleared historically for firewood, agriculture and levee building. As noted above, the impacts to riparian habitat in the Delta was focused primarily in the outer portions of the Delta. Urban development is causing further losses in the Central Valley as well as the Delta.

## HABITATS ASSOCIATED WITH DELTA LEVEES

The habitat types which are associated with levees can be categorized as follows:

- **Shaded Riverine Aquatic (SRA)** - this habitat type includes all vegetation which overhangs the water, regardless of tide stage as well as near shore and in-channel aquatic cover such as submerged logs, roots, etc.
- **Riparian forest** - includes trees greater than twenty feet in height typically with one or more understory layers (cottonwood, alder, sycamore, etc.)
- **Scrub shrub riparian** - includes trees and woody shrubs and vines (alder, willow, wild rose, box elder, wild blackberries) less than twenty feet in height.
- **Freshwater marsh** - includes cattail and tule marshes found along the drainage ditch at the landside levee toe and other areas at the interface of the levee and channel edge, and berms and berm islands.
- **Riverine** - includes vegetated shallow mudflats, shoals, submerged logs, and in water vegetation such as pondweed on the channel side of the levee.

Shaded Riverine Aquatic habitat has been recognized by the U.S. Fish and Wildlife Service (USFWS) National Marine Fisheries Service (NMFS) and Department of Fish and Game (DFG) as one of the most valuable habitat components of the riverine aquatic ecosystem of the Sacramento River system and Delta.

SRA habitat occurs in the nearshore aquatic zone where the adjacent riverbank supports riparian vegetation that either overhangs or protrudes into the water. It usually occurs, and has highest habitat values, along banks which have not been riprapped. However, in instances where woody vegetation has been allowed to recolonize riprapped banks, attributes of SRA habitat can become reestablished.

The productive interaction and synergism of terrestrial and aquatic habitat types associated with SRA result in a valuable cover type for fish and other aquatic organisms, providing a variety of microhabitats, composed of various flows, depths, cover, and food production. Riparian vegetation hanging over the water also shades the aquatic environment. Leaf and insect drop provides food and other essential nutrients to the aquatic ecosystem. Of particular note is the documented value of this natural, nearshore zone to juvenile salmon as they rear in and migrate through the Delta to the ocean.

As defined by the USFWS one or more of the following attributes are present in SRA 1) living roots, branches, and tree trucks exposed within the water; 2) fallen plant material, including logs, branches, and leaves within the water; 3) relatively irregular and uneven natural banks, often with many depressions, cavities, and crevices; 4) comparatively shallow, low-velocity areas near the shoreline; 5) more detritus and greater primary food-chain production than nearby unshaded area; and in certain instances, 6) lower water temperatures than comparable unshaded nearshore areas.

Riparian habitat, both riparian forest and riparian scrub shrub, are found on the water and land side of levees, berms, berm islands, and in the interior of some Delta islands. These habitats range in value from disturbed, sparse, low value habitat of relatively undisturbed, dense, diverse, high value habitat. The highest value riparian habitat has a dense and diverse canopy structure, and abundant leaf and invertebrate biomass. The lower value riparian habitat is frequently moved, disced, or sprayed with herbicides resulting in sparse, low diversity habitat structure. Riparian habitat is used by more vertebrate wildlife than any other Delta habitat type.

Riparian habitat is characterized by tree-dominated woodlands and forest or shrub/brush, made up of deciduous woody species. Dominant species in the overstory include cottonwood, sycamore, valley oak and tree willow, which may reach heights of 100 feet. The understory or shorter species include white alder, shrub willow, elderberry, ash and box alder. Blackberries and wild grape are common ground cover or vines.

Riparian woody species can survive seasonal, but not permanent, flooding. They are found on slightly higher ground of natural levees or other areas of sediment deposition in river floodplains. Riparian habitat is commonly found on the banks of waterways and man-made levees, which are, for the most part, artificially cleared.

Raptors (birds of prey), herons and egrets, and cavity nesting birds seek height, and nest or perch in riparian woodland trees. Riparian vegetation supports an abundant and diverse assemblage of insects in the canopy leaf litter, and tree and shrub bark. These insects are an important food source for fish populations such as the Sacramento splittail.

Freshwater marshes associated with levees in the Delta are both tidal and non-tidal. Tidal marshes, once the most widespread habitat in the Delta, are now restricted to remnant patches. "Tule islands" or "berm islands", and "berms" are principally found in Delta channels where the area between levees is wide enough or where substrates are deposited high enough for tules and cattails to survive. There are also remnant non-tidal marshes found in the interior of Delta Islands along toe drain ditches or in close association with seeps at the base of levees.

## HABITATS ON LAND PROTECTED BY DELTA LEVEES

The habitat types which are associated with the lands protected by the Delta levees can also be categorized into five types as described below:

- Agricultural
- Lakes and ponds
- Uplands
- Freshwater marshes
- Riparian

Agricultural lands in the Delta region include row crops, pasture, fallow lands and some orchards and vineyards. The present-day Delta is mostly farmlands, which comprise over 86 percent of the dry land surface area. The wildlife habitat value of these lands depends on crop types and the agricultural practices employed including flooding and tillage regimes.

The farmed wetlands of the Delta are critically important habitat for wintering waterbirds including shorebirds, geese, swans, ducks and sandhill cranes, supporting 10 percent of all waterfowl wintering in the state. During the winter, many fields are flooded with shallow water, enhancing their value to ducks, geese, and swans. The Delta farm acreage in corn has particularly good forage value for geese, swans, and cranes.

Agricultural fields also have populations of small animals such as rodents, reptiles and amphibians providing opportunities for raptor foraging. Non-flooded fields and pastures are also habitat for pheasants, quail, and doves.

The Delta and its agricultural lands protected by its extensive levee system, is an internationally significant wintering ground for waterfowl because of the remaining wetlands and shallowly flooded agriculture ground. The Delta is critical to four species of waterfowl, tundra swan, white-fronted goose, northern pintail, and canvasback. The Delta is the single most important wintering area in the Pacific Flyway for tundra swans and ranks second only to Chesapeake Bay in the entire continent. Estimates of the number of swans wintering in the Delta range from 30,000 to 38,000 annually, representing 32-40 percent of the Pacific Flyway population winters. Between 22,000 to 45,000 white-fronted geese winter in the Delta, composing about one-third of the flyway population. Of the white-fronted geese banded on the Yukon - Kuskokwim Delta in Alaska, approximately 17 percent winter in the Delta. Northern pintails are the most numerous waterfowl species found in the Delta.

Estimates of wintering populations, including the Suisun Marsh, vary from 200,000 to 1.4 million birds. State aerial inventories in the early 1950's counted some one million pintails on Staten Island alone. Almost 500,000 pintails, were counted in the Yolo Bypass in January 1973. Canvasback numbers in the Delta vary greatly, but approximately 10 percent of the flyway population can be found there. Although mallards are usually the second most

numerous duck species in the Delta, the midwinter flyway survey indicates that mallards are, on average, only one-tenth as numerous as pintails.

The northeast portion of the Delta is also one of the most important wintering grounds for the Central Valley population of the State listed threatened greater sandhill crane. In winter 1983-84, 53 percent of the population was in the Delta in December, and January, 76 percent of the population was on Staten Island, the DFG's Woodbridge Ecological Reserve, and the Cosumnes River areas. Islands throughout the Delta serve as important foraging areas with crane use primarily focusing on harvested corn fields.

The Swainson's hawk, a state threatened raptor species, breeds and winters in the Delta. Preferred habitat consists of tall trees for nesting and perching in proximity to open agricultural fields which support small rodents and insects for prey. Both pasture land and alfalfa fields support abundant rodent populations. One of the highest breeding densities of Swainson's hawks in the Central Valley is found in the region between Sacramento and Stockton, encompassing the eastern Delta.

Lakes and ponds such as Stone Lake near Sacramento and the "blow out" ponds on islands and tracts such as Venice Island and Webb Tract support simple invertebrate communities, riparian vegetation, and large numbers of waterfowl.

Upland habitats are found mainly on the edge of the Delta and consist primarily of grasslands with some remnants of oak woodland and savannah (grassland with scattered trees).

**DELTA LEVEE AND CHANNEL  
MANAGEMENT ISSUES**

**PERSPECTIVES OF STATE, FEDERAL  
AND LOCAL AGENCIES**

**M e m o r a n d u m**

Date September 17, 1993

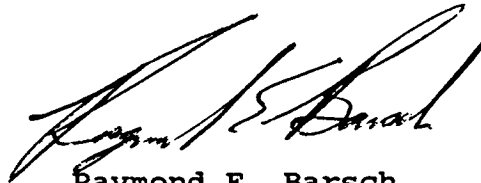
To Steve Yaeger  
Deputy Executive Officer  
Bay-Delta Oversight Council  
1416 Ninth Street, Suite 1306-3  
Sacramento, California 95814

From THE RECLAMATION BOARD

Subject Bay-Delta Oversight Council Briefing Paper Comments

Thank you for the opportunity to review your "Briefing Paper on Delta Levees." The Reclamation Board concurs with the discussion on Delta levees contained in the Paper. We would like to emphasize that the Board is responsible to the U.S. Army Corps of Engineers for operation and maintenance of the Sacramento River Flood Control Project levees in the Delta. These federal levees, which comprise about 35 percent of the Delta levees, are generally constructed and maintained to higher standards than the nonfederal levees. Even so, the ongoing Phase IV of the Sacramento River Flood Control Project System Evaluation has identified approximately 17 miles of federal levees within the Delta in need of repair to restore them to their original design. The U.S. Army Corps of Engineers, together with the Board and affected local reclamation districts, will be cost-sharing in these levee rehabilitation efforts.

If you have any questions, please contact me at (916) 653-5434.



Raymond E. Barsch  
General Manager

**SEISMIC SAFETY COMMISSION**

1900 K STREET, SUITE 100  
SACRAMENTO, CA 95814  
(916) 322-4917  
(916) 322-9476 FAX



September 15, 1993

Mr. Steve Yaeger  
Deputy Executive Officer  
Bay-Delta Oversight Council  
1416 Ninth Street, #1306-3  
Sacramento, CA 95814

Dear Mr. Yaeger:

Thank you for the opportunity to review the draft document entitled *Briefing Paper on the Delta Levees*. The following comments are those of the Commission staff and focus on the section in the document that addresses seismic stability issues for the Sacramento-San Joaquin Delta Levees. We believe the Delta area's vulnerability to earthquake damage must be considered seriously as you address existing and future development, water transport and other safety issues.

The briefing paper can be read to imply that earthquakes are not a concern. It states on page 1, paragraph three, that "there is no record of a levee failure, or even significant damage to a levee as a result of earthquake shaking." However, information presented in a February, 1985 issue of *California Geology* (pp. 39-44) does identify some revealing facts regarding damage to Delta levee vulnerability due to earthquake shaking:

- Several bridge embankments in the Delta failed along Middle, San Joaquin, and Mokelumne Rivers during the 1906 earthquake. These embankments were similar in composition to the present Delta levees but not as high.
- The 1906 earthquake may have weakened the Delta levees leading to extensive failures throughout the levee system during the flood of 1907.
- The 1983 Coalinga earthquake damaged several levees. This damage was described as "cracking" of levees. One feature was 1000 foot in length, 3 to 10 feet wide, and 10 to 15 foot deep. The Coalinga epicenter was 150 miles from the damaged levee.

- The Coyote Lake (1979), Livermore (1980),  
Pittsburg (1983), and the Morgan Hill (1984)  
earthquakes also apparently damaged levees in the  
Delta.

The earthquakes cited above were either small magnitude local events or distant earthquakes of moderate size. The damage caused by these earthquakes reinforces the information presented in the estimated levee damage susceptibility maps presented in Figures 8-2 and 8-6 of the August, 1992 Department of Water Resources report, "Seismic Stability Evaluation of the Sacramento-San Joaquin Delta Levees." Large "distant" earthquakes on the San Andreas, Hayward, Rogers Creek, or Calaveras and close by earthquakes along the coast range/Sierra Nevada boundary zone remain plausible hazards. Amplification factors of 1.0 and 1.6 are realistic estimates for the Delta where extensive levee damage is likely from moderate to strong ground shaking. The risk to development on or behind levees from ground failure and shaking should also be considered.

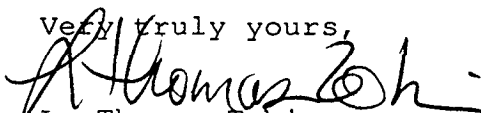
We strongly recommend that you address the implications of seismic hazards in the Delta on existing and future developments. You should identify areas expected to experience the strongest earthquake ground motion and ground failure and the implications of levee failure on land uses, the environment and fresh water transport.

We also recommend that you call for an overall earthquake emergency response and recovery plan. It should include procedures for rapidly coping with levee failures following a major distant or local earthquake. It also should clearly specify which organizations are responsible for repair of the Delta levees after a destructive earthquake. Several counties, the Corps of Engineers, the Department of Water Resources, local governments, and others all share various overlapping responsibilities for levees in the Delta. If a major earthquake destroys a portion of the levee system, it is unclear what organization would take the lead in repair efforts.

The Commission has not spent much time on the Delta due to other priorities and therefore cannot prepare a "perspective paper" at this time. We will, however, assist you any way it can in gathering seismic and geotechnical data regarding the Delta, working with someone who could write such a paper, and recommend the appropriate experts to review reports or advise the Council.

Should you need any additional assistance, please give contact Mr. Richard McCarthy of my staff.

Very truly yours,

  
L. Thomas Tobin  
Executive Director



REPLY TO  
ATTENTION OF

DEPARTMENT OF THE ARMY  
U.S. ARMY ENGINEER DISTRICT, SACRAMENTO  
CORPS OF ENGINEERS  
1325 J STREET  
SACRAMENTO, CALIFORNIA 95814-2922

September 8, 1993

Delta Planning Branch

Mr. Steve Yaeger  
Deputy Executive Officer  
State of California  
Bay-Delta Oversight Council  
P.O. Box 942836  
Sacramento, California 94236-0001

Dear Mr. ~~Yaeger~~: *Steve*

Thank you for the opportunity to critique the two draft briefing papers concerning Delta levees that you provided with your August 4 letter. Our comments are attached. After reviewing the briefing papers, we do not feel there is a need for the Corps to provide an additional "prospectives paper" on the issue of Delta levees.

If you have any questions regarding our comments or if we can provide addition information, please contact Mr. Ron Milligan of our Delta Planning Branch at (916)557-6726.

Sincerely,

Walter Yep  
Chief, Planning Division

Enclosure

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C-070292

DELTA PROTECTION COMMISSION  
P.O. Box 530  
Walnut Grove, Ca 95690  
(916) 776-2290

August 20, 1993

Steve Yeager  
Deputy Executive Officer  
Bay-Delta Oversight Council  
P.O. Box 942836  
Sacramento, CA 94236-0001

Subject: Comments on Briefing Papers on Delta Levees and Seismic  
Issues for Levees

Dear Mr. Yeager:

Thank you for forwarding the two draft briefing papers for my review. These papers have not been reviewed by the Commission, so these are staff comments only and do not reflect the positions or views of the Commission.

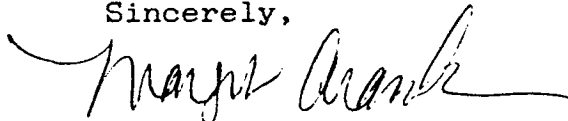
Generally, I believe the two papers are clear and understandable. As they are briefing papers, I can understand that more formal references were not included, however, it would be helpful to have included some additional footnotes.

One comment about the levee paper--there appears to be unresolved conflict regarding the "habitat value of the levees" and the rodent burrows and vegetation on the levees being one of the identified Failure Modes.

Regarding the seismic issues paper, there is obviously a key issue for the large areas of the Delta with peat soils; do the peat soils dampen or accelerate seismic activity? The current program to install four seismographs is thus very important. It would be helpful to have a more complete description of this program; the funding, the goals of the program, the location of the four seismographs, and the length of the study.

Please keep me informed of your programs.

Sincerely,



Margit Aramburu  
Executive Direct

September 7, 1993

Mr. Steve Yaeger  
Bay-Delta Oversight Council  
1416 Ninth Street, Suite 1306-3  
P.O. Box 942836  
Sacramento, CA 94236-0001

SUBJECT: Comments on BDOC's Briefing Paper on Delta Levee  
Stability and DWR's Review of Seismic Stability  
Issues for Sacramento-San Joaquin Delta Levees

Dear Mr. Yaeger:

Thank you for requesting our comments on the Bay-Delta Oversight Council's draft "Briefing Paper on Delta Levees" and the Department of Water Resources' draft "Review of Seismic Stability Issues for Sacramento-San Joaquin Delta Levees." The East Bay Municipal Utility District (EBMUD or District) has attached a Perspective Paper which describes the importance of Delta levee security to EBMUD's water supply and would like to offer the following comments with respect to the two documents.

**Comments on BDOC's Briefing Paper (August 1993)**

Page 15

Liquefaction from seismic forces should be listed as one of the levee failure mechanisms under the section entitled "Main Design Areas." Under the subsection entitled "Seepage Control," potential methods of seepage remediation, such as grouting, should be included.

Page 16

The section entitled "Design Procedures and Methods," should include an additional procedure, namely, the use of aerial photographs to delineate the location of historic river channels. Delineation of these historic channels would be useful in assessing areas with an accumulation of poorly consolidated to unconsolidated sediments resulting from cycles of deposition and erosion. These areas with poorly consolidated sediments may be sites for future levee failures.

375 ELEVENTH STREET, OAKLAND, CA 94607-4240, (510) 835-3000

P.O. BOX 24055, OAKLAND, CA 94623-1055

FOR INFORMATION: KATHERINE MCKENNEY, STUART FLASHMAN, ANDREW COHEN

JOHN A. COLEMAN, JOHN M. GIOIA, NANCY J. NADEL, KENNETH H. SIMMONS

Mr. Steve Yaeger  
September 7, 1993  
Page 2

**Comments on DWR's "Review of Seismic Stability Issues for  
Sacramento-San Joaquin Delta Levees" (July 1993)**

Page 2

The "Executive Summary" refers to the use of upstream reservoir releases in diluting and flushing out the intruded saline water in the event of Delta levee failures and inundation of islands. The report should note that there may be insufficient water stored in upstream reservoirs to dilute Delta waters in the event of earthquake-induced levee failures during low river flow conditions. In the event of an earthquake of that magnitude, municipalities would need the water stored in upstream reservoirs for drinking and fire-fighting, and it may not be feasible to plan on reservoir releases to dilute the Delta.

Page 15

EBMUD concurs with the probabilistic risk analysis performed by the Department of Water Resources. The District commissioned several seismic studies resulting in approximately the same peak rock acceleration (PRAs) within similar probabilities and exposure periods cited in the report.

Page 26

Figure 12 illustrates the summary of Liquefaction Analyses, commissioned by EBMUD, which graphically represent the estimated probabilities of exceedance for the onset of liquefaction within the region of the Mokelumne Aqueduct. It should be noted that this onset of liquefaction, as further defined in the report, appears to represent the Low to Moderate range of levee damage susceptibilities listed on page 25 of BDOC's briefing paper.

EBMUD appreciates the opportunity to comment on these reports and looks forward to receiving copies of the final version.

WR\LLT\BAY-DELTA\LEVEE.LTR

Mr. Steve Yaeger  
September 7, 1993  
Page 3

Please find attached to this letter a brief perspective paper for your consideration. If you have any questions or need additional information, please contact me at (510) 287-1121.

Respectfully submitted,

  
Jon A. Myers  
Managers of Resources Planning

Attachment

JAM:LLT:hs

WR\LLT\BAY-DELT\LEVEE.LTR

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## Perspective Paper

The security of the East Bay Municipal Utility District (EBMUD) water supply delivery system is essential to a population of 1.2 million in Alameda and Contra Costa Counties. EBMUD's three Mokelumne Aqueduct pipelines cross the Sacramento-San Joaquin Delta where they are vulnerable to damage from levee failure due to earthquakes or flooding. These risks could potentially disrupt water supply delivery for an extended period. In the event of an extended disruption, the limited water supply available from EBMUD's local reservoir would require severe rationing, up to 34% percent reduction in water use for a 7 to 11 month duration.

As part of its Water Supply Management planning effort, EBMUD has recently completed an Aqueduct Security Study. This Study concluded that there was a high probability of unacceptable outage due to seismic activities. Depending on an earthquake's intensity and proximity to the Delta, groundshaking could (1) result in liquefaction, a loss of strength in the water-saturated sandy soils which would weaken levee foundations and the soils surrounding the Mokelumne Aqueduct pipeline and (2) cause structural failure of the piles and supports under the elevated aqueducts. EBMUD is in the process of designing measures to strengthen the aqueduct and adjacent levees as part of its Aqueduct Upgrade Project.

Because of EBMUD's ongoing effort in developing methods to strengthen the Mokelumne Aqueduct system, the District is very interested in obtaining information pertaining to seismic stability issues for the Sacramento-San Joaquin Delta levees. EBMUD would like to obtain the Final Briefing paper developed by the Bay-Delta Oversight Council, along with perspective papers from other parties.

**DELTA LEVEE AND CHANNEL  
MANAGEMENT ISSUES**

**PERSPECTIVES AND ISSUES  
OF CONCERN TO RECLAMATION  
DISTRICTS**

# CALIFORNIA CENTRAL VALLEY FLOOD CONTROL ASSOCIATION

921 - 11TH STREET, SUITE 703 - SACRAMENTO, CA 95814  
PHONE (916) 446-0197 - FAX (916) 446-2404

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September 15, 1993

Mr. Steve Yaeger  
Deputy Executive Officer  
Bay Delta Oversight Council  
1416 Ninth Street, Suite 1306-3  
Sacramento, CA 95814

Subject: Peer Review of Draft Bay Delta Oversight Council Briefing  
Paper on Delta Levees

Dear Mr. Yaeger:

On behalf of the California Central Valley Flood Control Association, I would like to thank you for the opportunity to comment on your Briefing Paper on Delta Levees. The document adequately introduces the reader to problems associated with delta levees. However, as described below, we would caution against the manner in which the cost of recent levee rehabilitation projects compare to the Corps of Engineers 1982 Draft Feasibility Report on Delta Levees.

In several instances within the Briefing Paper it is stated that the Corps of Engineers estimated in 1982 that rehabilitation of delta levees would cost about 1 billion dollars or about \$2.06 million per levee mile. This figure is compared to the recent levee work on western delta islands which equated to a total cost less than the Corps estimates. One should be cautious when comparing the 1982 Corps estimates with recent levee work. The Corps of Engineers Draft Feasibility Report estimates included recreation and fish and wildlife enhancement features in addition to work performed on the levees. Levee work included flood walls and setback levees which are not typical of the recent western delta levee work. Levee costs also included increased freeboard due to wind fetch and ship wake, levee patrol roads and extensive bank protection. Land acquisition, damages and relocation of roads and bridges are also included. The Corps report also included

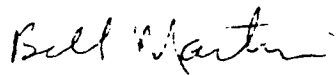
staged construction where levee work is continually performed up to 90 years in the future. Stages subsequent to the initial stage are required to compensate for long-term subsidence due to foundation consolidation.

We agree that use of on-island borrow material and bay-delta dredge material would be less costly than potential borrow considered in the Corps report, such as the Peripheral Canal, Los Vaqueros Reservoir and Montezuma Hills. If the new innovative design suggested in the paper indeed reduces the fill required to rehabilitate and maintain levees to the standards used by the Corps, then there will certainly be a cost savings.

The Briefing Paper does a good job of introducing the reader to delta levees. We would encourage that Council members continue to educate themselves on delta levees. The complexities and uniqueness of delta levees are as varied as the number of reclamation districts in the delta. Further investigation by Council members would be beneficial in understanding the complexity of the delta and its levee system.

Thank you again for the opportunity to comment on your Briefing Paper. At this time the Central Valley Flood Control Association does not choose to write or submit a perspectives paper. We feel that the amount of data digestible at one time is limited, however, we would be happy to offer a perspective in the future as the Bay-Delta Oversight Council continues its work.

Sincerely yours,



Billy E. Martin  
Manager



DIRECTORS  
George Biaz Jr.  
Rudy Moss  
Allen E. Zuckerman  
COUNSEL  
Dante John Nomellon  
Thomas M. Zuckerman

## CENTRAL DELTA WATER AGENCY

235 East Weber Avenue • P. O. Box 1461 • Stockton, CA 95201  
Phone 209/465-5883

September 3, 1993

Steve Yaeger  
Deputy Executive Officer  
Bay-Delta Oversight Council  
1416 Ninth Street, Suite 1306-3  
Sacramento, California 95814

Re: Briefing papers on Delta levees

Dear Sir:

Thank you for the opportunity to review and comment on the Briefing Paper on Delta Levees dated August 1993 and the Memorandum Report on Review of Seismic Stability Issues For Sacramento-San Joaquin Delta Levees.

I think both documents appear to reflect an ever-improving understanding of Delta levees and those preparing such reports should be commended.

### Briefing Paper On Delta Levees - August 1993

Page 2 - Levee Standards - The HMP standard levee height is one (1) foot above the 100 year flood, not one and five tenths (1.5) feet as shown.

Page 2 - Levee Standards - The FEMA standard levee height for Urban Development is three (3) feet above the 100 year flood, not one and five tenths (1.5) feet as shown.

Page 3 - The local district agreement on the HMP was subject to funding. It was expected that FEMA and NDAA disaster claims would be honored in a reasonably expeditious manner and that State Levee Subvention Funds would be available at a total of about 10 million dollars per year. Many FEMA and NDAA disaster claims from 1982, 1983 and 1986 have not yet been honored and the State Levee Subvention Funds have been sporadically provided with average annual levels less than expected. Aside from funding, other major obstacles were encountered. There was a new policy by the Department of Fish and Game that Districts would be subject to criminal prosecution for performing work on the waterside of the levees unless "Streambed Alteration" permits which imposed severe restrictions on levee work were first obtained. Due

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to this requirement alone, many levee projects were delayed one to two years. Also adding to the problem is the failure of the State Water Resources Control Board to provide a water quality certification so that the general Corps of Engineers permit could be renewed for dredging. FEMA appears to be satisfied with the good faith effort and progress of local districts. FEMA has orally informed the State and the local districts that the deadline will not be applied but rather a district by district evaluation of progress towards the objective will be substituted.

Page 3 and other pages where subsidence and peat soil are mentioned - It is important to understand that most of the Delta does not have peat soil. The Delta as defined in Water Code section 12220 contains about 738,000 acres. About 415,000 acres is referred to as Delta lowlands, those lands which are less than five (5) feet above sea level. Almost all the Delta uplands and much of the Delta lowlands initially had little or no peat soil. Due primarily to oxidation, it is believed that about 2 inches per year of peat soil has been lost. Since most of the Delta has been subjected to drainage for about 100 years, about 200 inches or about 16.5 feet of peat has oxidized away. Because of oxidation, areas which once had 16.5 feet or less of peat soil now don't have any. Subsidence of the land surface and levee problems related to subsidence affect only the levee systems in the lowest portions of the Delta and in many cases only portions of those levee systems.

If you look at the Department of Water Resources Thickness of Organics Map, which I think is based on measurements taken in 1976, you will see the areas containing organics. I have attached a copy of such map showing the measured thickness. The DWR's 1993 Delta Atlas at page 26 contains a colored map showing the general areas and ranges of depths. The areas containing more than 10 feet of peat in 1976 comprise about 70,000 acres. Another way to view it is that about 10 to 15 percent of the Delta lands remain subject to further significant subsidence. The best way to keep Delta levee problems in perspective is to try to establish the actual number of miles of problem levees in each category. With proper understanding and a unified effort by all the stakeholders including fish and wildlife and environmental interests, the Delta levee problems can be solved.

Page 15 - Slope and Foundation Stability. One important aspect which I did not see mentioned is levee alignment. Waterside erosion due to wavewash, scour, rodents, falling vegetation or other causes generally results in the center-lines of levees being moved landward. The landward pro-

gression results in fills being placed on relatively unconsolidated foundation materials, thereby adding significantly to the quantity of fill required and extending the time required for placement. In some cases, a better strategy might be to modestly add fill in the waterward direction. For the lower Delta, foundation materials waterward of the present day levee centerline should be significantly more consolidated than those in the landward direction. Figure 3 on Page 3 of the Briefing Paper and Figure 2 on Page 6 of the Seismic Stability Report should reflect a greater movement of the centerline of the levee in a landward direction. The foundation consolidation should be shown to be greater near the current waterline than at the current centerline.

Page 23 of the Briefing Paper dealing with Levee Funding should mention the funding provided through the State's Natural Disaster Assistance Act (NDAA). During the period of 1980 through 1986, the NDAA was the primary mechanism whereby the State provided a significant share of funding towards Delta levees. This was very important to Federal assistance. The Federal attitude was that it shouldn't help a State if the State wasn't trying to help itself. Pages 81 and 82 of the 1993 Delta Atlas show NDAA expenditures of about 26.5 million dollars along with the FEMA 65 million and local 5.7 million. The local expenditures do not include the expenditures on the work not eligible for disaster assistance or the interest paid by local districts on borrowings to pay disaster-related claims pending reimbursement. Prior to 1988, the State Levee Subvention Program was quite modest. The August 1987 DWR Delta Atlas shows for the period 1981-86 total State subventions of 7.29 million dollars or an average of about 1.2 million dollars per year. In 1973, the program was funded at about \$200,000.00. Significant State funding for the Delta levee subventions did not occur until after the voter rejection of SB 200 (Peripheral Canal legislation). I know there is a list of the State Levee Subvention Program funding by year, but I could not find my copy. Dave Lawson in DWR probably can provide the listing.

Hopefully, the above is helpful.

Yours very truly



DANTE JOHN NOMEILLINI  
Manager and Co-Counsel

DJN:ju  
Enclosures

RECLAMATION DISTRICT NO. 2026  
WEBB TRACT  
3697 MT. DIABLO BOULEVARD, SUITE 120  
LAFAYETTE, CALIFORNIA 94549  
TELEPHONE 510-283-4216

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September 1, 1993

Mr. Steve Yaeger  
Deputy Executive Officer  
Bay-Delta Oversight Council  
1416 Ninth Street, Suite 1306-3  
Sacramento, CA 95814

Dear Mr. Yaeger:

Your letter of August 4, 1993 directed to David Forkel of Reclamation District No. 2026 has been forwarded to me for review and response. Your letter enclosed two position papers developed by the Department of Water Resources, one entitled Briefing Paper on Delta Levees dated August 1993 and the other entitled Review of Seismic Stability Issues for Sacramento-San Joaquin Delta Levees dated July 1993 marked as a draft.

The Department of Water Resources is to be commended for its efforts, particularly its recent efforts relative to geotechnical issues in the Delta.

The Briefing Paper on Delta Levees properly identifies the most serious problem as being in those areas where deep peat soils or other very soft soils underlie the present levee system and where Delta levee heights have become relatively tall. What the paper does not point out is that of the 550,000+ acres in the Delta protected by levees, far less than half is threatened by significant soft soil problems and the continuing problem of subsidence. This element of the "broken Delta" analysis would be best directed toward the islands where the levees are functionally the tallest and the remaining peat soils are the deepest.

The report properly identifies that continued subsidence in the peat soil areas will require the continued lowering of the drainage ditch water elevation to preserve an aerobic soil condition for growing crops now prevalent in the Delta. Lowering the water surface in the interior of an island functionally increases the structural height of the levee. Such a change does not necessarily require that material be added to the top of the levee, but it definitely requires that the landside geometry of the levee be altered to resist levee breaching forces.

Mr. Steve Yaeger  
September 1, 1993  
Page 2

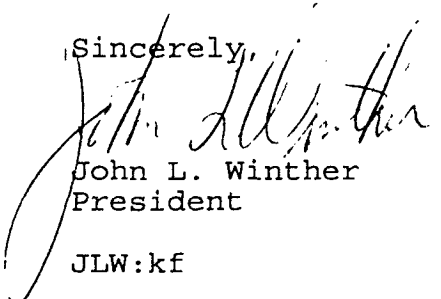
If sand underlies the peat soil, which is a common situation in many parts of the Delta, boils or wet spots can appear at great distances from the levees as the depth of the peat is decreased unless an aggressive plan of drainage is employed. It is important, however, that this seemingly never-ending spiral of subsidence and attendant levee stability be tempered by the fact that a relatively small percentage of the Delta islands and levees are suffering from this ongoing trend. Management practices in the entire Delta need not be developed on the worst-case basis.

We believe that the near-shore dredger cuts that have developed over the years to maintain Delta levees in many instances could be filled with ship channel dredge spoils to reduce seepage, improve levee stability and provide near-shore shallow water. This, in turn, would encourage the growth of tules. All of these factors taken together not only improve levee stability, but serve to add shaded riverine habitat and stabilize the soil just below the water line on the outside of the levees. The additional shaded riverine habitat could serve to mitigate for habitat loss due to certain levee maintenance work.

The briefing paper on seismic stability issues clearly points out the importance of establishing whether or not Delta soils amplify or dampen seismically-induced ground motion. The results of the Department of Water Resources' ongoing studies will be of great interest.

Thank you for the opportunity to submit our comments on the Department of Water Resources briefing papers. Your effort to receive input from such a wide variety of commentators is commendable. We look forward to receiving and commenting upon the balance of the briefing papers.

Sincerely,



John L. Winther  
President

JLW:kf

## RECLAMATION DISTRICT NO. 548

1101 West Tokay Street

Lodi, CA 95240

Bill Morais, Pres.  
Ray Coldani, Trustee  
Michael Scriven, Trustee

Robert Sternfels, Counsel  
Tom Rosten, Engineer

September 19, 1993

Mr. Steve Yeager  
Deputy Executive Officer  
Bay-Delta Oversight Committee  
1416 Ninth Street, Suite 1306-3  
Sacramento, CA 95814

Dear Mr. Yeager:

Thank you for requesting that this District review the Draft Briefing Paper on Delta Levees. The document was referred to me for engineering evaluation. My comments follow:

- o The document covers most of the critical issues that presently affect the Delta levee system. It contains many similes which help the lay person understand some very difficult technical issues. I particularly liked the simile on page 12 where the underlying peat foundation was compared to toothpaste.
- o The document should contain a "Recommendations" section. This section should contain the following recommendations:
  - Long term cost sharing arrangements beyond Year 2000 between the State and the local Reclamation Districts need to be implemented by the Legislature in order to assure the timely maintenance and rehabilitation of the non-Project levees.
  - The Legislature should create an emergency fund to pay for the repair of a levee failure and the subsequent recovery of an inundated tract or island.
  - The Legislature should set a speed limit of no more than five miles per hour for boats which traverse identified sloughs and small channels in order to reduce the erosion damage to adjacent levees and channel berms. This action would reduce levee maintenance costs and help preserve the extraordinary wildlife habitat that exists on the channel islands.
  - The various State agencies with jurisdiction over the channel islands should develop and implement a plan to preserve the channel islands and enhance the habitat on each of these islands. The Department of Water Resources should be the lead agency.
- o The draft document alludes to catastrophic levee failure and indicates that emergency funding from FEMA may be available if a failed levee(s) met Hazard Mitigation Plan standards. However, if FEMA declares that a failed levee did not meet HMP standards and withholds emergency funds, then there is a distinct probability that a failed levee which protected a small Reclamation District, such as Woodward Island, would not be repaired and the island would remain inundated. The Mildred Island levee failed and the owners did not have the financial ability to repair the levee break and reclaim the island. As a result, that island is still inundated. In my opinion, the State needs to set up an emergency fund of approximately \$20,000,000 to pay for the repair of failed levees and the recovery of an inundated island or tract. A cost sharing mechanism could be built into the authorization of such a fund by the Legislature. (A fund this large could repay the recovery costs of three or four islands.
- o The draft document glosses over the controversy that has developed between the Reclamation Districts and the Department of Fish and Game regarding vegetation management on the existing levees, especially those belonging to Reclamation Districts that participate in the levee subventions program set up by S.B. 34. DFG has been interpreting a long term loss of habitat as any vegetation disturbance

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resulting from levee maintenance activities which does not recover in one year. In my opinion, this is not what the legislature meant when it enacted S.B. 34. However, since the legislation did not contain a definition of "a long term loss of habitat", DFG has employed its rule making authority to provide a very restrictive definition of the controversial phrase. To me, the phrase "long term" defines a period that is more lengthy than one year. For instance, long term health care does not define long term as one year. If the phrase "long term" when applied to loss of vegetation on a levee covered a period of four or five years, then I believe that the controversy between the Reclamation Districts and the DFG would disappear.

However, as long as DFG continues to use its narrow interpretation of "long term loss of habitat", then, many District's will have their hands tied because mitigation requirements are so difficult to meet. Necessary maintenance will be forgone while brush continues to grow on their levees. The ultimate result will be a levee failure! Thus, DFG will have preserved some brush for a short while that would have grown back in four or five years while setting up a catastrophic levee failure. If the island or tract that is inundated by such a failure has limited financing, then the levee failure results in the formation of another inland sea.

The appendix to the proposed FEMA/State agreement that you referred to on page 3 of the draft document could be helpful if DFG would bless it. My experience with DFG has been that mid level bureaucrats, with their own personal agendas, exert great influence over the policies adopted by that agency. In a nut shell, they appear to believe that the levees can sustain an unlimited amount of brush without risking levee failure. This is not true, as the draft document so ably points out. Levee inspectors and engineers must be able to observe the condition of the levee so that corrective repairs can be undertaken in a timely manner to avoid crises conditions during flood events. Corrective repairs usually require the removal of vegetation so that such repairs can be made. DFG appears to oppose the removal of such vegetation unless it can be mitigated. This opposition continues even though it may lead to the failure of the levee.

The controversy is fueled by DFG's desire to control the actions of the Reclamation Districts which are responsible for the maintenance of the non-Project levees. Persons with a non-engineering, non-construction background (mid level bureaucrats) want to dictate the manner in which levees are maintained. Right now, preservation of brush and trees is given a higher priority than levee maintenance. DFG needs to reverse these priorities. They should work with the Districts to make sure that needed maintenance is accomplished. That would set up the atmosphere for a cooperative effort to preserve and enhance wildlife habitat where opportunities exist.

- o No mention was made in the draft document regarding the habitat values that exist on the channel islands that are situated throughout the Delta streams and sloughs. Many rare and endangered species live on these islands. However, many of the islands are disappearing as a result of erosion damage caused by wave action. Much of the wave action is attributable to wakes from passing boats. (In my opinion, boat caused erosion is greatly accelerating the disappearance of these channel islands.) I believe that DFG, in concert with other involved State agencies, should develop a program to preserve and enhance the wildlife habitat on these islands. Some of the best habitat within the legal Delta is located on these islands. The briefing paper should contain a complete discussion of the preservation of these channel islands.
- o The draft document does not discuss the role that near shore tule berms play in combatting levee erosion. My observations lead me to conclude that tule berms dampen the energy force carried by each wave and thus attenuates erosion damage to the levee. The growth of tules along the water side toe of the levee should be encouraged by the Delta Reclamation Districts. A discussion of the role of tule berms in protecting the levee should be included under Erosion Control on page 17 of the draft document.
- o The draft document contained no discussion of the role that the dredging of material from adjacent streambeds has played in the longtime maintenance of the Delta levee system. It does not point out that recent restrictions on dredging resulting from protection of endangered species, such as winter run

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Salmon and Delta Smelt, have inhibited the ability of the Reclamation Districts to maintain the non-Project levees. Only two months of the year (July & August) are now open to dredging, after a site specific dredging permit has been acquired from the Corps of Engineers. It is predictable that those who own dredges will move them to another part of the United States because they will not be able to afford to keep them in the Delta to work only two months out of each year. This will result in fill material being imported to the Delta levees from outside borrow areas or from borrow pits developed on each island. Rough calculations indicate that it will be from twice to three times as costly to furnish and place a cubic yard of fill material on a levee as it would be if the material were acquired by dredging.

Mr. Robert Sternfels, Secretary and Counsel for this District, is presently on vacation. Upon his return, he will forward additional comments regarding the draft document. His comments will address some of the legal issues involved in Delta levee maintenance and improvement.

Sincerely,



Thomas J. Rosten  
District Engineer

cc: Robert Sternfels, Secretary  
Bill Morais, President  
Mike Scriven, Trustee  
Ray Coldani, Trustee

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